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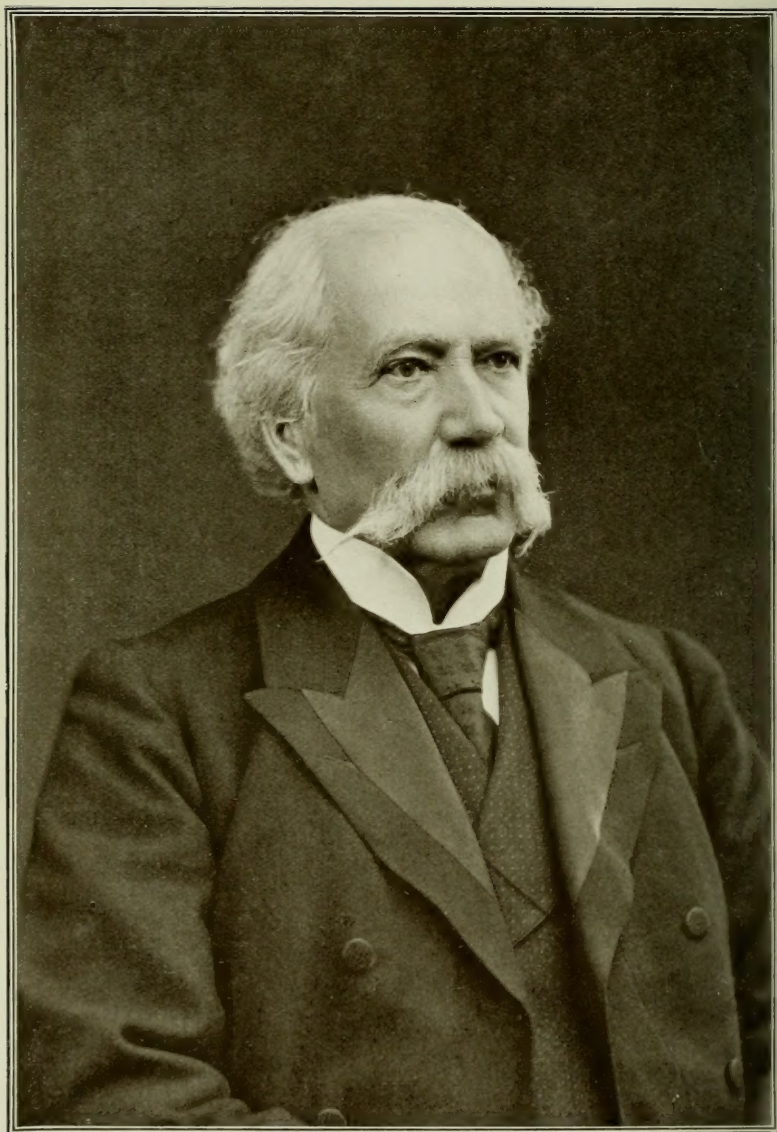
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PRESIDENT

Frontispiece

No. 1

1912

THE JOURNAL OF THE INSTITUTE OF METALS

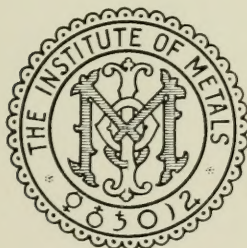
VOLUME VII

EDITED BY

G. SHAW SCOTT, M.Sc.

SECRETARY

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127343
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LONDON

PUBLISHED BY THE INSTITUTE OF METALS

CAXTON HOUSE, WESTMINSTER, S.W.

1912

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Printed by BALLANTYNE, HANSON & Co.
At the Ballantyne Press, Edinburgh

THE INSTITUTE OF METALS

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CAXTON HOUSE, WESTMINSTER, S.W.

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THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the Institute of Metals was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday and Wednesday, January 16 and 17, 1912, Sir GERARD A. MUNTZ, Bart., retiring President, occupying the chair on Tuesday, January 16, prior to the declaration of the result of the ballot for officers for the year 1912. Afterwards, and on Wednesday, January 17, the chair was occupied by Professor A. K. HUNTINGTON, Assoc.R.S.M., Vice-President, in the absence, owing to illness, of Professor W. GOWLAND, F.R.S., President.

The SECRETARY (Mr. G. Shaw Scott, M.Sc.) read the Minutes of the previous meeting, held in Newcastle on Wednesday and Thursday, September 21 and 22, which were found to be a correct record, and were signed by the Chairman.

The SECRETARY then read the following Report of the Council upon the work of the Institute during the year 1911:—

REPORT OF COUNCIL.

THE Council have pleasure to report that the year 1911 has witnessed considerable and important advances in the Institute's undertakings. A notable feature has been the commencement of actual experimental work by the Corrosion Committee, some details of whose work are given subsequently in this Report.

THE ROLL OF THE INSTITUTE.

The Council note with satisfaction the steady increase in the membership of the Institute. The number of those on the roll of the Institute on December 31, 1911, was as follows:—

Fellow	1
Honorary Members	3
Ordinary Members	555
Student Members	27
Total	586

The following table shows the development that has taken place since the Institute was founded in 1908:—

	Dec. 31, 1908.	Dec. 31, 1909.	Dec. 31, 1910.	Dec. 31, 1911.
Fellows . . . . .	...	...	1	1
Honorary Members . . . . .	...	1	3	3
Ordinary Members	350	492	524	555
Student Members	5	12	23	27
Total	355	505	551	586

The Council regret to have to record the death during the past year of Mr. E. Ristori, a Member of Council, whose valuable work for the Institute was highly appreciated by his colleagues. There have also to be recorded with regret the deaths, which took place during 1911, of the following three prominent members of the Institute: Mr. D. J. Dunlop, Mr. J. Preston, and Mr. W. H. Thompson.

GENERAL MEETINGS.

During 1911 three General Meetings were held. The Annual General Meeting took place in London on January 18, the Chair being occupied by Sir Gerard Muntz, Bart., who delivered his Presidential Address. On the day prior to the meeting a visit of members took place to the yard of the Thames Iron Works, Shipbuilding and Engineering Company, Limited, where members were able to inspect H.M.S. *Thunderer* in the course of construction. On January 18 the following papers were read and discussed:—

1. "On the Present State of our Knowledge of the Corrosion of Non-Ferrous Metals and Alloys, with Suggestions for a Research into the Causes of the Corrosion of Brass Condenser Tubes by Sea Water." By G. D. BENGOUGH (Liverpool).
2. "On Some Practical Experience with the Corrosion of Metals." By Engineer Rear-Admiral J. T. CORNER, C.B. (London).
3. "On a New Critical Point in Copper-Zinc Alloys; its Interpretation and Influence on their Properties." By Professor H. C. H. CARPENTER (Manchester) and C. A. EDWARDS (Middlesbrough). With an Appendix on "The Nature of Solid Solutions," by C. A. EDWARDS.
4. "On Some Tests on White Anti-friction Bearing Metals." By H. J. HUMPHRIES and Professor C. A. SMITH (London).
5. "On the Adhesion of Electro-Deposited Silver, in Relation to the Nature of the German Silver Basis Metal." By Professor A. MCWILLIAM and W. R. BARCLAY (Sheffield).

The occasion of the next General Meeting of the year was the May Lecture, which was delivered on May 12, 1911, by Dr. G. T. Beilby, F.R.S., on the subject of "The Hard and Soft States in Metals," the full report of which will be found in the *Journal*, vol. vi. The Council have pleasure in reporting that the 1912 May Lecture will be delivered by Sir J. A. Ewing, K.C.B., F.R.S.

The Autumn Meeting was held at Newcastle-on-Tyne on September 20, 21, and 22. Most admirable arrangements were made for this meeting by an influential Local Reception Committee, of which the Hon. Sir C. A. Parsons, K.C.B., F.R.S., was Chairman, and Dr. J. T. Dunn, Honorary Secretary; and the meeting was most successful in every way. The following papers were read and discussed at Newcastle-on-Tyne on September 20 and 21:—

1. "On Non-Ferrous Metals in Railway Work." By GEORGE HUGHES (Lancashire).
2. "On the Electrical Conductivity and Constitution of Alloys." By Dr. W. M. GUERTLER (Germany).
3. "On the Mechanical Properties of Hard-drawn Copper." By D. R. PYE (Oxford).
4. "On Volume Changes in the Alloys of Copper with Tin." By J. L. HAUGHTON and Professor T. TURNER (Birmingham).
5. "On the Failure of a Brazed Joint." By Professor H. LOUIS (Newcastle-on-Tyne).
6. "On the Alloys of Aluminium and Zinc." By Dr. W. ROSENHAIN and S. L. ARCHBUTT (Teddington).
7. "Further Notes on the Nature of Solid Solutions." By C. A. EDWARDS (Middlesbrough).
8. "On the Corrosion of Brass, with Special Reference to Condenser Tubes." By P. T. BRÜHL (West Africa).

September 22 was devoted to an excursion to the mouth of the Tyne and back, for which purpose a steamer was kindly placed at the disposal of members by the Tyne Improvement Commissioners.

The Council desire to record their indebtedness to the Institution of Mechanical Engineers for the courtesy shown to the Institute of Metals in again allowing the Annual General Meeting and the May Lecture to be held in their building at Storey's Gate, Westminster, S.W.

COMMITTEE MEETINGS.

The three Standing Committees, known respectively as the Finance and General Purposes Committee, the Publication Committee, and the Corrosion Committee, have met regularly throughout the year, and several Occasional Committees, appointed by the Council for the consideration of special matters, have also met. The following new Committees were appointed during the year: The Library and Museum Committee, and the Abstracts Subcommittee.

THE BEILBY RESEARCH PRIZE.

The Council report with much pleasure that Dr. G. T. Beilby, F.R.S., in accordance with the promise contained in his May Lecture, has offered a Research Prize for the best contribution to our knowledge of "foam-cell structure," a question which the Lecturer stated "may have an important practical bearing on foundry practice." A Special Committee has been appointed by the Council to discuss with Dr. Beilby a suitable scheme of research and other details.

CORROSION COMMITTEE.

Considerable progress has been made with the work of this Committee. In January 1911, at the request of the Committee, Mr. Bengough presented a Report, which contained a detailed review of the existing literature on the corrosion of copper and brass, together with suggestions for the first experiments on the research to be carried out under the control of the Committee. This Report, together with the discussion thereon, was printed in full in the Journal of the Institute, No. 1, 1911, vol. v., pages 28 to 114 inclusive. A subscription list was opened for the purpose of defraying the expenses connected with the research, and so far £302 13s. 6d. has been subscribed or promised.

The Committee has considered very carefully the details of the apparatus to be used in this research, and has paid particular attention to the need for imitating as closely as is possible, on an experimental scale, the conditions which obtain in a surface condenser on board

ship. In the first instance deep-sea water will be used, though later on brackish and sewage-contaminated waters from rivers or docks will be employed. Special attention will be devoted to ascertaining which of the deposits that are liable to occur in a tube are most harmful.

Alloys of at least four different compositions will be, in the first instance, employed in the experiments. The plant has been designed in such a way that most of the factors which may possibly influence corrosion can be varied independently, so that the exact effect of each may be ascertained.

The plant has been erected in the Metallurgical Department of Liverpool University, and was inspected and taken over from the contractors on December 14, at a special meeting of the Committee. The first "run" with the plant, which is expected to last many months, was begun early in January 1912. The results will be reported in due course to the Institute.

An extensive laboratory research will be carried out by Mr. Bengough at the same time as the experiments above referred to with the view of ascertaining the chief causes of corrosion; the comparative results of the two methods of work promise to be of much interest and value.

The Committee has decided also to collect as much information as possible from the actual users of condenser tubes, and to this end has drawn up a schedule of questions upon a number of points which seem to them to have an important bearing on corrosion problems. The schedule is being widely circulated amongst users of tubes, and the Committee is most anxious that the questions should be replied to as far as is possible, both by users who have not, as also by those who have, suffered from corrosion troubles. The Committee will be glad to receive samples of good and bad tubes, which samples, after inspection by the Committee, will be placed in the Institute Museum at Caxton House.

It is most desirable that the corrosion plant should be operative continuously night and day; and as the cost of this will be considerable, further funds for the purpose are urgently required. The Committee trust, therefore, that members, shipowners, and others who have not already subscribed will kindly help by their contributions.

BIRMINGHAM LOCAL SECTION.

Mr. G. A. Boeddicker was re-elected Chairman of the Birmingham Section.

The new rules for the admission of Associates to the Section came

into force at the beginning of this session, and the Section now consists of 50 Members and 17 Associates.

The first session proved to be very successful, and some excellent papers were read, as the following list will show :—

1st and 2nd Lectures.—"An Introduction to Metallography." By O. F. HUDSON, M.Sc.

Paper.—"A Visit to some Rolling Mills in America." By G. A. BOEDDICKER (*Chairman*).

Paper.—"Annealing of Non-Ferrous Metals." By T. VAUGHAN HUGHES, Assoc.R.S.M.

The average attendance at these meetings was 42; 21 members and 21 visitors.

The following programme has been arranged for the session 1911-1912 :—

1911.

Oct. 10. Discussion on Annealing Furnaces, opened by the Chairman.

Nov. 14. Paper, "The Gases in Brass Strip Ingots. Notes on the reasons for using dressed moulds, and a description of the apparatus employed in the investigation." By JOHN CARTLAND, M.Sc.

Dec. 12. Paper, "The Uses of Electricity in Brass and Copper Rolling Mills." By Messrs. MILNS and ANDERSON, City of Birmingham Electric Supply Department.

1912.

Feb. 6. Exhibits and Notes on Specimens, illustrating the Influence of Certain Impurities on the Forging Qualities of Copper at a Red Heat. Presented by L. ARCHBUTT.

Mar. 12. Paper by F. C. A. LANTSBERRY, M.Sc.

April 9. Paper on "Cold Rolling Mills." By W. H. A. ROBERTSON.

May 14. Annual General Meeting.

PUBLICATIONS.

Two volumes of the Journal were published in 1911—Volume V. being issued in June and Volume VI. in December. These contained 841 pages of letterpress, plates, and numerous illustrations in the text. The Council are pleased to note that the value of the Journal is being appreciated more and more each year, as the sales of the Journal, both to members and non-members, have been greatly increased during the past year, 48 volumes having been sold between July 1, 1909, and June 30, 1910, and 163 volumes during the year ending June 30, 1911. The Transactions, or Proceedings, of the following Societies or Institutions are regularly received in exchange for the Journal of the Institute :—

American Electro-Chemical Society.

American Institute of Mining Engineers.

Bureau of Standards, Washington (Department of Commerce and Labour).

Chemical Society.
 Faraday Society.
 Imperial Institute.
 Institute of Marine Engineers.
 Institution of Automobile Engineers.
 " " Civil Engineers.
 " " Electrical Engineers.
 " " Engineers and Shipbuilders in Scotland.
 " " Mechanical Engineers.
 " " Mining and Metallurgy.
 " " Naval Architects.
 Iron and Steel Institute.
 Junior Institution of Engineers.
 Königliches Materialprüfungsamt, Berlin.
 Royal Society of Arts.
 Society of Chemical Industry.
 Staffordshire Iron and Steel Institute.
 West of Scotland Iron and Steel Institute.

LIBRARY.

During the year many valuable contributions have been received from members and others towards the Library, which was commenced in 1910. The following presentations to the Library have been received, and are gratefully acknowledged by the Council :—

Title.	Presented by—
American Institute of Electrical Engineers, Proceedings of the, for 1899 to 1910.	E. S. Reid, Esq.
"Catalogue of Wheeler Gift." Vols. i. and ii.	E. S. Reid, Esq.
"Copper Handbook." Vol. x.	Horace J. Stevens, Esq.
"Electro-Deposition, the Principles of." By S. Field.	Longmans, Green & Co.
"Handbook of Metallography." By Dr. W. M. Guertler.	The Author.
Institution of Civil Engineers, Proceedings of the. Vols. cxxi.—cxxiv. (inclusive), cxxxi.—clx. (inclusive), clxii. and clxiii., clxv.—clxxii. (inclusive), clxxiv.—clxxviii. (inclusive), and Index to Vols. cxix.—clxx. (inclusive).	A. C. Newcombe, Esq.
Institution of Electrical Engineers, Journal of the. Nos. 33 to 44 (inclusive), bound; and the Proceedings from 1904 to 1910 (inclusive), unbound.	E. S. Reid, Esq.
"Metallurgy." By Ad. Fenchel, D.Sc.	John Bale, Sons, & Danielsson, Ltd.
"Metallurgy of Tin." By Professor H. Louis, M.A., D.Sc., Assoc.R.S.M.	The Author.
"Mineral Industry of Rhodesia." By J. P. Johnson.	Longmans, Green & Co.
"Modern Electric Practice." Vols. i. to vi. (inclusive).	E. S. Reid, Esq.
"Ninth Report to the Alloys Research Committee of the Institution of Mechanical Engineers."	F. C. A. H. Lantsberry, Esq.
"Practical Guide to Iron and Steel Works Analyses." By Walter Macfarlane, F.I.C.	Longmans, Green & Co.

The books are available for the use of members in the Library attached to the offices at Caxton House, Westminster, S.W.

DELEGATES TO CONFERENCES.

In connection with the Optical Convention, 1912, Professor W. Gowland, F.R.S., was appointed by the Council to act as their representative. The Council was represented at the preliminary meetings held in London in connection with the International Congress of Applied Chemistry, 1912, by Professors W. Gowland, F.R.S., and A. K. Huntington, Assoc.R.S.M.

ANNUAL DINNER.

The Second Annual Dinner of the Institute was held on January 17, 1911. There was an attendance numbering about 175, amongst whom were many distinguished guests, including the Presidents of allied institutions, the Rector of the Imperial College of Science and Technology (Sir Alfred Keogh, K.C.B., LL.D.), the Chief Superintendent of the Royal Ordnance Factory (Sir H. F. Donaldson, K.C.B.), and the Director of Naval Stores (Sir John Forsey).

Mr. ARNOLD PHILIP, B.Sc., Assoc.R.S.M., in moving that the Report of the Council be received and adopted, said that although he had not had the opportunity of studying the Report, and had only been able to form an opinion upon it while the Secretary had been reading it to the meeting, it was clear from the statistics given that the Institute showed marked signs of vigorous life. He thought the Council were very much to be congratulated upon the increase in membership. A great deal of interest had been created by the discussion of papers, by the extraordinarily interesting lectures which had been delivered by experts on special metallurgical subjects, and the prize which Dr. Beilby had so kindly offered for an investigation in regard to the structure of metals.

Mr. LEONARD SUMNER, M.Sc., after seconding the motion, inquired whether the Council could make arrangements for the members of the Institute to receive copies of the papers that had been read before the Birmingham Local Section, as they seemed to be of very great interest.

The PRESIDENT, in reply to Mr. Sumner's question, said it must be dealt with by the officers of the local section. It was outside the province of the Institute to circulate the papers of any local section other than those which were embodied in the *Journal*. He was sure, however, that Mr. Boeddicker, the Chairman of the Birmingham Local Section, would be only too pleased to oblige any member who desired to know what was going on in Birmingham. He only hoped that Manchester, now that it had seen what was going on in Birmingham, would do the same as Birmingham had done, and establish a local section.

The motion for the reception and adoption of the Report was then carried unanimously.

Professor THOMAS TURNER, M.Sc. (Honorary Treasurer), presented the following Report and Balance Sheet for the year ending June 30, 1911:—

It is satisfactory to report that despite the steadily increasing expenditure of the Institute, its finances, owing to increased membership, continue in a satisfactory condition. The financial year opened with a credit balance of £326 19s. 5½d., and closed with a balance, also to credit, of £456 5s. 0½d., showing an increase of £132 5s. 7d. A very nearly identical amount was received for the sale of Journals, which has proved to be a steadily increasing source of income. The cost of incorporation has since been paid, and will be included in the next account. The amount is within the sum anticipated by the Council.

In the Corrosion Research Fund, up to June 30, 1911, subscriptions amounting to £251 12s. 3d. had been received, while only £10 2s. 6d. was spent in preliminary expenses. There was, therefore, a balance in hand of £241 9s. 9d. on July 1. The greater part of this money will be spent before December 31, 1911, and some additional subscriptions will be required if the work is to be satisfactorily accomplished.

When allowance is made for every known liability, the net balance in the hands of the Institute on July 1, 1911, on the ordinary account, was £377 3s. 5½d. There was, in addition, library and office furniture, a large stock of Journals, and the balance in the Research Fund above mentioned. The Institute is, therefore, to be congratulated on its present financially sound and progressive condition.

INSTITUTE OF METALS.

10

Annual General Meeting

TREASURER'S ACCOUNT OF RECEIPTS AND PAYMENTS FOR YEAR ENDING JUNE 30, 1911.

RECEIPTS.		PAYMENTS.	
To Balance brought forward from last Account—		By Expenses of Meetings	£58 17 10
Lloyd's Bank Deposit Account	£257 2 4	Journal	466 7 0
" " General	51 8 6		
Cash in hand of Secretary	12 15 1½	" MANAGEMENT EXPENSES—	
" " Treasurer	2 13 6	Office Staff	£359 3 11
		Rent, Rates, &c.	203 1 3
Subscriptions	£323 19 5½	Printing and Stationery	82 12 10
Sales of Journal	1290 14 2	Postages, Travelling, & Sundries	114 10 8
Subscriptions towards Sir W. White's Portrait	132 18 10		
Clyde Trip Tickets	5 5 0	Sir W. White's Portrait	759 8 8
Sale of Dinner Tickets	29 8 6	Expenses of Clyde Trip	5 5 0
Interest on Deposit Account	53 0 6	Dinner	32 10 0
	12 1 7	" Bank Charges	66 14 6
" CORROSION FUND—		" Balance—	2 0 0
Subscriptions	£251 12 3	Lloyd's Bank Deposit Account	£269 3 11
Less Sundry Disbursements	10 2 6	" General	164 2 4
	241 9 9	Cash in hand of Secretary	17 6 5½
		" Treasurer	5 12 4
		" CORROSION FUND—	456 5 0½
		Balance at Lloyd's Bank	241 9 9
			£2088 17 9½

I hereby certify that I have audited the Accounts of the Institute of Metals for the Year ending June 30, 1911, and in my opinion the above Account is a correct statement of the Receipts and Payments for that period.

GEO. G. POPPLETON,

CHARTERED ACCOUNTANT,

BIRMINGHAM, LONDON, AND SHEFFIELD.

(Honorary Auditor.)

September 5, 1911.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M., suggested that the members should be informed what proportion of the £241 the balance in the hands of the Corrosion Research Committee on July 1st, had since been spent.

Professor TURNER stated that, in addition to the £10 2s. 6d. which had been spent on preliminary expenses, the Committee had paid £150 on account, and certified a further £75 for payment for the purchase of the plant for the installation. The total amount that had been thus spent was £235 out of the £277 that had been collected. The balance of approximately £42 was available for the cost of running, and that amount would be more than exceeded before the end of twelve months. The Committee would therefore require additional contributions if it was to carry on the work, and it must be continuous if it was to be valuable.

The PRESIDENT moved that the Honorary Treasurer's Report be received and adopted.

Professor CARPENTER seconded the motion, which was carried unanimously.

The PRESIDENT said that he desired, on behalf of the members, to move a cordial vote of thanks to the Honorary Treasurer for his services during the past year. Professor Turner had done a very great deal of hard work, which he need hardly say was voluntary. The Treasurer was not paid for his services, and the Institute could not afford to offer him his value if he were paid. He was sure the members were very much indebted to Professor Turner for the large amount of work he had done on their behalf.

The resolution of thanks to Professor Turner was carried by acclamation.

ELECTION OF OFFICERS.

The PRESIDENT called upon the Secretary to announce the result of the ballot for the election of members to replace the retiring President, three Vice-Presidents, and five Members of Council (inclusive of the Honorary Treasurer), the list as read being as follows:—

*Annual General Meeting**President.*

Professor W. GOWLAND, F.R.S., Assoc.R.S.M., London.

Vice-Presidents.

SUMMERS HUNTER	North Shields.
Engineer Vice-Admiral Sir H. J. ORAM, K.C.B., F.R.S.	London.
Sir H. A. WIGGIN, Bart.	Birmingham.

Hon. Treasurer.

Professor T. TURNER, M.Sc., Birmingham.

Members of Council.

R. KAYE GRAY	London.
R. S. HUTTON, D.Sc.	Sheffield.
W. MURRAY MORRISON	London.
A. E. SEATON	London.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M., in proposing a hearty vote of thanks to the President and Council who had presided over the work of the Institute for the last session, said it seemed hardly necessary, in view of what those gentlemen had done, to make any comment on their work, except that of great praise. He was sure all the members would agree with him that the Council had done uncommonly good work. Governmental and regulative duties connected with a new Institute were, as any one who had any experience of the sort knew, very onerous, and the members trusted they would always have a similar class of gentlemen to preside over the destinies of the Institute.

Mr. E. L. RHEAD, M.Sc.Tech., in seconding the resolution, said the best endorsement of the work of the Council was the progress which had been made during the year, and the advancement not only in the membership but in the funds of the Institute. The way in which the *Journal* was appreciated was, he thought, indicated by the increase in the sales that had taken place; and the *Journal* was undoubtedly one of the great advantages of the Institute.

The motion was put to the meeting by Mr. Vaughan Hughes, and carried with acclamation.

The PRESIDENT thanked the members, on behalf of the Council and himself, for the very kind vote of thanks that had just been passed. He had not consulted his colleagues as to what he should say in reply, but he knew he was making a correct statement when he said that they had all zealously worked in the service of the Institute, and that those who were continuing in harness would work equally well in the future.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates who had been duly elected members of the Institute as a result of the ballot taken in December 1911 :—

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Abbott, Robert Rowell	Peerless Motor Car Co., Cleveland, O., U.S.A.	Metallurgical Engineer	Sir Henry Wiggin. T. Turner. G. A. Boeddicker.
Brown, William Meikle	46 Bede Burn Road, Jarrow-on-Tyne	Secretary and Gen. Manager, The Bede Metal and Chemical Co., Ltd., Hebburn	Pitt Becker. H. W. Keiffenheim. E. C. Keiffenheim.
Dunsmuir, George Augustus	Govan Engine Works, Govan, Glasgow	Engineer	J. T. Milton. H. A. Ruck-Keene. C. Buchanan.
Jenkins, Ivor Owen (Student)	"Gwynfa," Pen-y-wern, Neath, South Wales	Partner in firm of Phosphor Bronze Brass Founders	F. Johnson. A. Sinclair. B. H. Morgan.
Lazarus, William	193 Regent Street, W.	Motor Engineer	H. Bevis. W. Hyman. A. G. Simkins.
Letcher, William Whitburn	84 Queen Elizabeth Walk, Lordship Park, N.	Secy., Williams, Foster & Co., and Pascoe, Grenfell & Sons	Pitt Becker. P. W. Smith. W. N. Stanley.
Manthorpe, Robert Salton	Brisbane, Queensland, Australia	Metal Merchant	P. Scott Leggatt. T. Turner. G. A. Boeddicker.
Michie, Arthur C., D.Sc.	The Wallsend Laboratories, Neptune Road, Wallsend-on-Tyne	Technical Chemist	Leonard Sumner. F. Tomlinson. T. Kendrew.
Powell, Harry (Student)	169 Rookery Road, Handsworth, Birmingham	Metallurgical Chemist	F. C. A. H. Lantsberry. W. L. Baylay. L. J. Meyrick.
Rao, Seshagiri Raghavendra	Mysore Geological Dept., Bangalore, Mysore, India	Geologist and Metallurgist	T. Turner. O. F. Hudson. Sir G. Muntz, Bt.
Taylor, William Ivan	Kynoch Limited, Umbogintwini, Durban, S. Africa	Metallurgist and Technical Chemist	G. H. Stanley. M. T. Murray. V. G. Stevens.

The PRESIDENT said he had great pleasure in asking the members to accord a hearty vote of thanks to the scrutineers Professor Huntington and Mr. J. T. Milton, for the work they had performed.

The resolution was carried by acclamation.

ELECTION OF AUDITOR.

The PRESIDENT, in moving that the retiring honorary auditor, Mr. G. G. Poppleton, be re-elected, said he had carried out his work excellently; and inasmuch as the Institute were paying nothing for his services, he was sure the members could not do better than ask him to serve again. He had much pleasure in moving Mr. Poppleton's re-election, and that he be thanked for his services during the past year.

Mr. W. ROBINSON seconded the motion, which was carried unanimously.

The PRESIDENT said he had to make an announcement which he was sure the members would receive with great regret, namely, that owing to his unfortunate state of ill-health, the President-Elect, Professor Gowland, was unable to take the chair that afternoon. He was sure that every one present would be extremely sorry to hear that announcement, not only because of its reason, but also because Professor Gowland's presence at the meeting would have given very great pleasure. That being the case, it would be necessary, in accordance with the Rules of the Institute, for a chairman of the meeting to be elected, now that he had ceased to be their President.

Professor THOMAS TURNER desired, in the first place, to re-echo what the President had said in reference to the great regret of the members at the enforced absence of Professor Gowland. They had looked forward with very great pleasure to hearing his address, remembering the admirable lecture the new President had given on a previous occasion. To many present Professor Gowland was an old friend; they

sympathised with him in his illness and wished him a speedy recovery. Under the circumstances he felt sure the members could not do better than ask Professor Huntington, a Vice-President, to take the chair at the present meeting, and he had much pleasure in proposing that Professor Huntington be requested so to do.

Professor CARPENTER seconded the motion, which was carried unanimously.

Sir GERARD MUNTZ then vacated the chair, which was taken for the remainder of the meeting by Professor Huntington.

VOTE OF THANKS TO SIR GERARD MUNTZ.

The CHAIRMAN (Professor Huntington) said he had great pleasure in asking the members to accord a very hearty vote of thanks to Sir Gerard Muntz, who had fulfilled the duties of the chair for the past two years, and had carried on the work of the Institute in a way which had promoted its interests in a very satisfactory manner. During that time many of those present had had an opportunity of judging for themselves of the way those duties had been carried out by Sir Gerard at the various meetings, but they did not know the amount of work he had done at the Council meetings and the numerous Committee meetings. He had exercised a great deal of tact, and had been very considerate to everybody; he had considered not only the interests of manufacturers, but the interests of professional and scientific men, and it was by keeping those three bodies in perfect harmony that the real interests of the Institute were promoted. That Sir Gerard had done in the most admirable manner. He therefore had the very greatest pleasure in asking the members to accord a hearty vote of thanks to their Past-President, which he was sure they would do by acclamation.

Mr. W. H. JOHNSON (Vice-President), in seconding the motion, said it was a very happy thought on the part of Sir William White when he suggested to the Council that

the right man to follow him in the chair was a practical metallurgist—a manufacturer; and there was not a manufacturer of brass and copper whose name was so well known, not only in the British Isles but the world over, as that of Muntz. In that way the Institute found a most worthy successor to its very able first President, and the thanks of all the members were certainly due to him for the work he had carried out. Sir Gerard Muntz had married a somewhat scientific Institute to the practical everyday workers in brass and copper. They knew that with Sir Gerard Muntz as President they would not merely hear scientific papers, but that his presidency would result in the problems every day confronting the worker in metals being brought forward, and the practical side would ever be emphasised. The lasting thanks of the members were due to Sir Gerard for having done that. The Past-President began very well in his Presidential Address, and he further carried on his good work every time he rose to make remarks from the chair on the papers that had been read or observations that had been made.

The resolution was then put to the meeting and carried by acclamation.

Sir GERARD MUNTZ, Bart., in reply, said he was much touched by the kind way in which the vote of thanks had been accorded to him for his two years' service in the chair. When he was called upon to take the position of President, he did so with very great diffidence, and he confessed it was not without a little anxiety that he finally accepted the position. It was an office the like of which he had not previously undertaken, and that in itself was something to make him hesitate. Further than that, he could not fail to realise the importance of the position which he was asked to fulfil, because it was not as though he was taking up the presidency of an old-established institute, but of a new institute with a very few years' life behind it. As he said at the time the members were good enough to elect him to the position, he felt that he was following an exceptionally good man in Sir William White, and he thus had a very difficult task to perform. He was

therefore in considerable anxiety as to what the upshot of his venture would be. He could only say that the results had been much more satisfactory to himself than he ever anticipated they would be, and he trusted they had been equally satisfactory to the members. He had received so much help and kindness from his colleagues on the Council, and also from the Members of the Institute, that whenever he looked for assistance and advice he had always obtained it, and the path had thus been made easier for him. One of the difficulties that he foresaw had proved to be more of a bogey than a reality, namely, that controversies would arise between the various sections of the Institute, science *versus* practice, and that there might be difficulty in smoothing matters over. But as a matter of fact he experienced very little difficulty in that respect. There had been a certain amount of criticism in the Press and elsewhere with regard to the utility of the Institute. It had been sometimes suggested that it was drifting too much towards the scientific side, and that it was not sufficiently practical. As the President it was his duty to try and do the best for the Institute in every respect. As a manufacturer he felt that he could use his own judgment as well as anybody else on that side of the question, and if the statement had been made that the Institute was too practical and not scientific enough, he might have thought the opinion was worth consideration. But as a manufacturer himself he was in a position to judge whether the Institute was getting too scientific or whether it was not. As he was bidding farewell to the Institute as President, he could speak probably more freely than he could during the time that he occupied that position, and he therefore wished to tell the Institute quite openly, speaking as a manufacturer with a good many years of practical knowledge behind him, that far from being too scientific, the Institute had yet long steps to go in a scientific direction. The Institute might leave it to the practical men to let the gentlemen in the scientific world know when they were getting too scientific for them. They would not hesitate to make remarks on that subject if papers were read that were too abstruse for the practical men. But it would be for the manufacturer to pick out from all the

words of wisdom which were laid before him the practical utility of the various suggestions; and the manufacturer in his turn would, he hoped, lay before the Institute the practical answer to the scientists' papers. He was quite certain the Institute had done an enormous amount of useful work for practical men. When he joined the Institute four years ago, he did it as a kind of experiment in more or less "fancy goods"; he did not anticipate that he was going to get much out of it. He thought at the time that if other people joined the Institute he might just as well be in the hunt too. He told the members quite candidly that at the time he did not anticipate he was going to get value for his money. He wished to say now, however, that he was entirely mistaken. Although he thought he knew a good deal about metals when he joined the Institute, he was now aware that he knew a great deal less than he thought he did. He had learned more from the Institute in three years than he thought it was possible for him to know. He had learned to know that he knew nothing, and he had learned to know how much there was to know. When he was elected President of the Institute it was, at that time, if he might say so without making any invidious remarks, somewhat like a pioneer or a prospector in a strange country looking for a mine. The prospector landed on a strange coast; he did not know which way to look, what he was going to do, or what was going to happen to him. There were all sorts of savages around him and he did not know what would be his fate. He thought the Institute was, however, in a much better position at the present time. It had a lot to do; it had not yet found the gold mines that it was looking for, but it had discovered in what direction it ought to look for them. Looking back over the papers that had been read before the Institute during the last two or three years, he thought everybody must realise that a very large amount of knowledge had been disseminated amongst the members, and terms which to many were, in the first instance, more or less vague so far as scientific research was concerned, had now become household words. When their friends the professors now got up and used long words, the practical men were no longer at a loss to understand what

they meant; it was not necessary for them to go home and look at a technical dictionary for the purpose. They were now better able to understand them, and had been placed in a much better position by the marriage of science with practice, of which Mr. Johnson had spoken. He felt sure that if the Institute progressed on the lines along which it had so far gone that each year it would become more valuable both to the scientific and to the practical men; and in that way, by working together, science and practice would, as had often been the case, be a mutual aid one to the other. He said that as a practical man, and he hoped scientists would be able to say the same hereafter. He thanked the members from his heart for their very kind vote of thanks, and assured them that it had been an immense pleasure to him to occupy the position of President. He left the presidential chair with mixed feelings. He was somewhat relieved to be out of harness and able to listen peacefully to what his friends and colleagues were saying without always thinking of what he would have to say in reply, and seeing that others always said and did the right thing. But it was also a matter of regret to him that he no longer occupied the chair. He felt that the Institute in electing Professor Gowland as its President had adopted a first-class man for the position. He was a man on totally distinct lines from either of his predecessors. He would be a scientific President, whereas the Institute's first President was on the consumer's side, and its second President on the manufacturer's side. The members had therefore tried the whole rota, and he trusted that as a result of Professor Gowland's election the Institute would be still further developed on scientific lines, and it would be for the practical men to assist more freely than they had hitherto done. He thought his successor would find the Institute in a most prosperous condition. In conclusion, he again thanked the members most heartily for their kindness to him during his term of office.

Mr. J. H. ROBINSON said he had not the pleasure of knowing the President, Professor Gowland, but they had all been told of his illness. Sympathy was always very precious to those

who were sick, and he would therefore like to move that a telegram be sent from the meeting conveying the sympathy of the members with the President in his illness, and their hopes for his speedy recovery.

Mr. LEONARD ARCHBUTT seconded the motion.

The CHAIRMAN thought that the motion was a very proper one, which would meet with general approval, and upon being put the resolution was carried by acclamation.

INAUGURAL ADDRESS.

The SECRETARY, in the absence of the newly-elected President, read the latter's Inaugural Address, at the conclusion of which

The CHAIRMAN (Professor Huntington) said that he was sure it would be the wish of the members that a vote of thanks should be conveyed to Professor Gowland for the address he had written. It was on different lines from those that were generally prepared, and he was sure the members were very pleased to have something a little different by way of an address. The President had studied archaeology for a great many years on the metallurgical side mainly, so that his address was a very useful and interesting contribution to the subject.

Dr. WALTER ROSENHAIN, in seconding the motion, said it was a great misfortune that the President was not able to be present at the meeting, to add the charm of his personality to the interest of the words which he had written. He thought that all the members appreciated the exceptionally interesting address. The historical aspect of metallurgy, and still more its archaeological aspects, had always possessed a strong fascination for himself personally, and it was a curious coincidence that he had first come into contact with Professor Gowland years ago at a meeting of the Anthropological Institute, where a metallurgical question had been discussed,

which to some extent bore on the subject of the President's address. More recently he (Dr. Rosenhain) had an opportunity of analysing an ancient Chinese coin, and he would be much interested in comparing that analysis with the data given in the address.

He only wished to express his personal appreciation of the address and also that of the members; not only those present here to-day, but also of those who would read the address in the *Journal*.

The resolution having been carried by acclamation, the meeting was adjourned at 5 P.M. until 10.30 A.M. on Wednesday, January 17, 1912.

SECOND DAY'S PROCEEDINGS.

WEDNESDAY, *January 17, 1912.*

At the adjourned meeting, which was again presided over by Professor Huntington in the absence of the President, Professor W. Gowland, F.R.S., papers were read by Mr. Arnold Philip, B.Sc., Assoc.R.S.M. (Admiralty Chemist); Professor H. C. H. Carpenter, M.A., Ph.D. (Manchester); Professor T. Turner, M.Sc. (Birmingham); Mr. G. D. Bengough, M.A. (Liverpool); Dr. W. Rosenhain, B.A. (National Physical Laboratory); Mr. F. Johnson, M.Sc. (Swansea); and Mr. R. H. Greaves, B.Sc. (Swansea). A paper by Professor Carl A. F. Benedicks and Mr. Ragnar Arpi (Stockholm) on "A Metallographic Hygroscope" was taken as read.

Each paper, with the exception of the latter, was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the Chairman, to the respective authors.

CONCLUDING BUSINESS.

The CHAIRMAN moved the following resolution:—"That the best thanks of the Institute be and are hereby tendered to the Council of the Institution of Mechanical Engineers for their courtesy in permitting the use of their rooms on the

occasion of this meeting," and said he was sure all the members would agree that the Institute was in a very favoured position in being able to use such an excellent set of rooms.

Professor CARPENTER seconded the motion, which was carried by acclamation.

Professor CARPENTER said that before the members separated he was sure there was one thing they would like to do, namely, to pass a vote of thanks to the Chairman, Professor Huntington, who, as they all knew, took up the position at very short notice owing to Professor Gowland's unfortunate illness. Under Professor Huntington's guidance the discussion had gone particularly well. Personally he did not remember a series of discussions that had gone better; and speaking as one who came under the Chairman's genial criticism during the proceedings, he had all the greater pleasure in moving the vote of thanks.

Dr. GWYER seconded the motion, which was put to the meeting by Professor Carpenter, and carried with acclamation.

The CHAIRMAN having briefly acknowledged the compliment, the proceedings terminated at 5.30 P.M.

COPPER AND ITS ALLOYS IN EARLY TIMES.*

PRESIDENTIAL ADDRESS.

By WILLIAM GOWLAND, Assoc.R.S.M., F.R.S.

(EMERITUS PROFESSOR OF METALLURGY AT THE ROYAL SCHOOL OF MINES).

WITH the discovery of metals, and notably the application of copper and its alloys in Neolithic times, we have one of the great turning points, if not the greatest, in the history of human development, the first-birth of the germs of that civilisation and culture to which we have attained at the present day. The discoveries of the properties of steam and electricity and their applications to our industries and other practical purposes of life we are apt to regard as wonderful and epoch making, yet when we compare them with the results which have followed the discovery of metals, they are but trifling and insignificant.

The order in which the metals were discovered was not the same for every region, as their ores are very capriciously distributed in the world, and it is extremely probable, if not absolutely certain, that the metals which occur native, *i.e.* those which occur as metals in nature, must have been first known to the men inhabiting the localities in which they occurred. The metals so occurring most frequently are gold and copper. The former is much more widely distributed than the latter, and must have been the first metal to be known in many regions.

It is, however, one of the most worthless metals for practical purposes, so that until the rise of Greek and Roman civilisation but little use was made of it. Copper, too, we only find in use to a very limited extent, as it was not well suited for the construction of weapons or useful implements. On the other hand, its alloy with tin afforded a metal which in

* Delivered at Annual General Meeting, London, January 16, 1912.

many physical properties could only be surpassed by iron or steel. According to the views of several ancient writers, Lucretius and Poseidonius, so momentous a discovery as that of metals contained in ores must needs have been brought about by no uncommon cause.

According to them a conflagration consumed forests which covered the outcrop of metalliferous veins, reducing the metals and bringing them to the notice of man, but there are no grounds for such inference. The discovery of metals other than "native" had no such poetic origin, but was brought about in a more commonplace and more humble way. It had its origin in the domestic fires of the Neolithic Age.

The extraction of the common metals from their ores does not require the elaborate furnaces and complicated processes of our own days, as pieces of ore, either copper carbonate or oxide, cassiterite, cerusite, or mixtures of these, and even iron oxides which by chance formed part of the ring of stones enclosing the domestic fire, and which became accidentally embedded in its embers, would become reduced to metal. The camp fire was, in fact, the first metallurgical furnace, and from it, by successive modifications, the huge furnaces of the present day have been gradually evolved.

First, a shallow cavity would be formed in the hearth of the fire for the reception of the molten metal, and this would be made larger as time went on and larger quantities of metal were required by deepening it or by surrounding it with a higher wall of stones. Furnaces of precisely this primitive form survived in Derbyshire up to the seventeenth century. In Japan the furnace for smelting copper, tin, and lead ores, a mere hole in the ground, which was in universal use there up to 1858, and is still extensively employed, is as simple and rude as that of the men of the Bronze Age.

The alloys of copper and tin during the early Metal Age, and even somewhat later, were obtained not by melting together copper and metallic tin, but by the reduction of oxidised copper ores containing tin-stone, or of copper ores to which tin-stone was added. As it has been stated by several continental archaeologists that when a copper ore containing tin ore is smelted the tin does not enter into combination with

the copper, but passes into the slag, I have made several experiments under the conditions which were available to prehistoric man, which completely disprove their statements.

A furnace of the simplest form, merely a hole in the ground, was constructed in my laboratory at the Royal School of Mines (Fig. 1). The fuel used was charcoal. A mixture of copper ore (green carbonate) and tin-stone was smelted in it, and a copper-tin alloy, a bronze containing 22.0 per cent., of tin was obtained.

The experiment was repeated several times, and in every case copper-tin alloys were obtained. See Appendix for details.

This experiment proves indisputably that when a copper ore containing tin ore was smelted by primitive man, a bronze consisting of copper and tin was the result.

The shape and structure of the lumps of copper which have been found in the founders' hoards* of the Bronze Age afford valuable evidence as to the size of the rude smelting furnaces, the method of smelting, and the manner in which the metal was removed from the hearth.

These lumps are always fragments of rudely disc-shaped cakes of about 8 inches to 10 inches in diameter, and 1½ inch in thickness, having the largely columnar fracture of copper when broken near its solidifying point.

They show that the furnace was simply a small shallow hole or hearth scooped in the ground, about 10 or 12 inches in diameter, and that the operation of smelting must have been conducted as follows:—A small charcoal fire was first made in the hearth, and when this was burning freely a layer of ore was spread over it, and upon this a layer of charcoal, then alternate layers of ore and charcoal were added in sufficient quantity to yield a cake of copper. The fire was doubtless urged by the wind alone in the earliest times, but later by some kind of bellows.

When all the charge had melted, the unburnt charcoal and

* Founders' hoards, many of which have been unearthed in this country and in Europe, contain generally worn-out or broken implements, waste castings, and rough lumps of copper apparently brought together for recasting. In some the objects are new and ready for use or are in an unfinished state. They appear to have been the stock-in-trade of itinerant founders. A flat axe made of the alloy is in the British Museum.

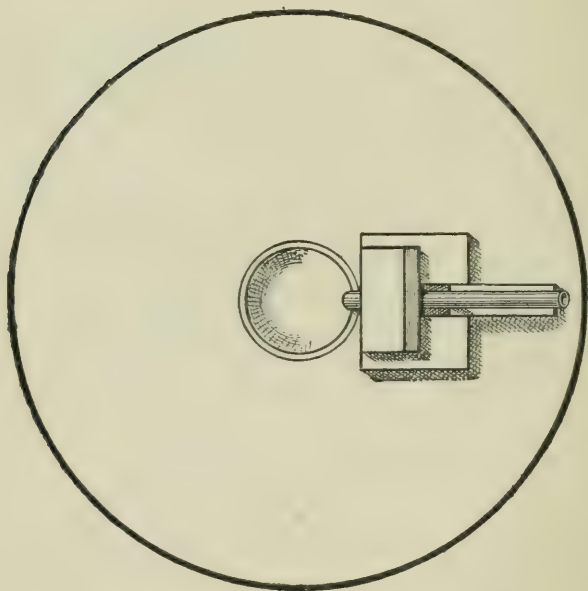
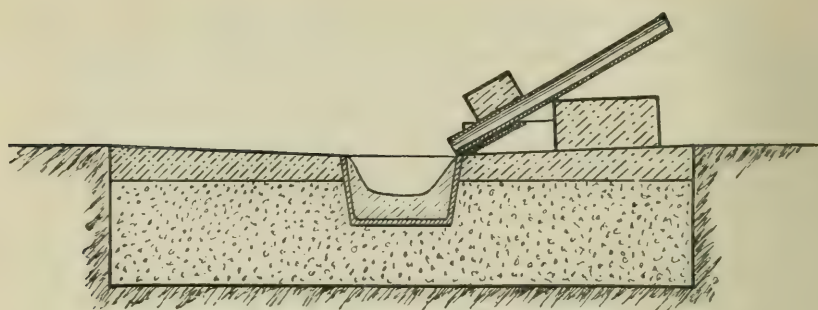


FIG. 1.—Primitive Furnace constructed at the Royal School of Mines.

the slag were raked off. The metal was not laded out, but was allowed first to solidify, and at the moment of solidification was rapidly pulled out and the cake broken up at once on a large stone. In Korea, at the copper mine of Kapsan, this primitive method of removing the copper from the furnace still survived when I travelled through the country in 1884.

The method of smelting copper ores in the primitive furnace which has survived in Japan from prehistoric times closely resembles that of the Bronze Age. A description of it will be found in my May lecture, 1910.*

The copper of the Bronze Age resembles modern blister copper in composition, but, unlike it, it often contains only traces of sulphur. When sulphur is present in the crude metal only in traces it undoubtedly indicates that the metal had been obtained by smelting oxidised ores.

The percentage of copper in several characteristic specimens ranges from about 97·0 to 99·0.

The following, Nos. 1 and 2, are complete analyses which I have made of two specimens from Ireland. No. 3 is one by Dr. Helm of a specimen from Posen :—

	No. 1.	No. 2.	No. 3.
	Per Cent.	Per Cent.	Per Cent.
Copper	96·99	98·95	99·16
Tin	0·08	0·17	0·05
Lead	0·06	Trace	0·03
Iron	0·30	0·20	0·08
Nickel	Trace	Trace	0·02
Arsenic	2·17	Trace	0·51
Antimony	Nil	Nil	...
Silver	0·21	0·35	...
Sulphur	Trace	Trace	0·03

From its high percentage of copper and comparative freedom from impurities, except arsenic, the Posen specimen must have been obtained either from a very pure ore or been submitted to a refining process.

In Ireland and one or two districts in Europe the earliest implements are of copper, in North America of native copper, but wherever the copper ores contain tin they are of a copper-tin alloy.

* *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 21 et seq.

I will now ask for your attention to the earliest alloys of copper and tin, those of the Bronze Age. In the production of these alloys in the earliest part of the Age, copper ores containing cassiterite can alone have been used; it is obvious, therefore, that the percentage of tin they contain must have varied with the percentage of cassiterite in the ore and the regularity with which the smelting operations were performed. Even in the later period of the Bronze Age, when the alloys were made by smelting the copper ore with cassiterite, alloys of definite composition can only have been accidentally obtained. Further, it is very questionable whether the metal tin was ever employed in making the alloys until the Iron Age was well advanced, as this metal has never been found in the founders' hoards. Consequently the implements and weapons are of very varied composition, at first generally containing but little tin, less than 3 per cent., but later having that metal frequently in satisfactory proportions for the uses for which they were intended.

A curious feature of the alloys of which the early weapons were made in Hungary is the presence of antimony as an important constituent instead of tin. This doubtless arose from the alloys having been prepared by smelting the antimonial copper ores which occur in that country. A notable example analysed by Dr. Helm had the following composition:—

	Per Cent.
Copper	91·12
Antimony	4·48
Tin	0·78
Nickel	0·61
Arsenic	0·32
Lead	1·63
Silver	0·45
Iron	0·49
Sulphur	0·12

Axes made of these alloys would be fairly serviceable on account of the hardness produced by antimony in copper. We hence find them in use, with antimony largely replacing tin, until late in the Bronze Age.

It has been frequently stated that the alloy used by the men of the Bronze Age generally consists of copper and tin

in the proportions of 9 to 1. I have hence compared the analyses which have been published, with the following results:—

Early Weapons and Implements—57 Analyses.

In 25 the Tin ranges from about 8 to 11 per Cent.

„ 6	„	„	„	11	„	13	„
„ 26	„	„	„	3	„	8	„

Later. (Palstraves and Socketed Axes)—15 Analyses.

In 13 the Tin ranges from about 4·3 to 13·1 per Cent.

„ 2 „ was about 18·3 per Cent.

Spear and Lance Heads.

In 5 the Tin ranges from about 11·3 to 15·7 per Cent.

Still later. Swords—23 Analyses.

In 14 the Tin ranges from about 8 to 11 per Cent.

„ 12	„	„	„	12	„	18	„
„ 7	„	is less than 9 per Cent.					

It is obvious, therefore, that these statements do not accurately represent the facts. And if we consider the different uses to which they were put, it is evident that no single alloy could be equally suitable for all. For certain uses an implement of copper, or of an alloy containing but little tin, would be efficient. On the other hand, for a sword or dagger certain physical properties are essential that are not needed for an axe; thus, whilst 10 per cent. of tin or somewhat less would be satisfactory for the latter, a higher percentage, say from 11 to 14, would be required for the former. It is worthy of note that these proportions appear to have been frequently attained, and for this the men of the later Bronze Age are deserving of great credit as metallurgists and workers in metal.

The difficulties the earliest men had to contend with were extremely great, for it is self-evident that alloys of definite composition could not be ensured by the early practice of smelting mixtures of ores. It would seem, therefore, that when we find weapons or implements of suitable composition for their intended use, some physical tests must have been applied to the furnace product before it had been used for their manufacture.

Some typical examples of flat bronze axes in the British Museum are shown in Plate I, Nos. 1, 2, 3, 4, and 5. Each

of these I have analysed, and their composition is given in the following table:—

TABLE II.—*Bronze Flat Axes, British Museum.*

Locality.	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Nickel, per Cent.	Arsenic, per Cent.	Antimony, per Cent.	Silver, per Cent.	Sulphur.
1. Taxley Fen, Huntingdonshire . . .	89·72	8·99	Trace	0·16	0·11	0·68	0·15	0·09	Nil.
2. Yorkshire (Butterwick) . . .	87·97	10·74	Trace	0·10	0·06	0·56	0·15	0·16	...
3. Cambridgeshire . . .	87·41	11·04	Trace	1·22	0·11	Trace	Nil	Trace	...
4. Plumpton Plain, near Lewes . . .	86·79	11·34	Trace	0·14	0·37	0·78	0·31	0·17	{ Manganese, trace.
5. Near York . . .	85·83	11·73	1·21	0·10	0·14	Nil	Nil	Trace	
6. Ireland . . .	86·20	12·52	Trace	0·19	Nil	0·68	0·26	0·21	...

We will now pass on to a brief consideration of the methods followed by prehistoric man for the manufacture of his weapons and implements. Practically all copper celts were cast in open moulds, as if cast in closed moulds they would be more or less vesicular and worthless, except when the copper contained arsenic, tin, antimony, zinc, or nickel in not less proportions than 1 per cent., or an excess of cuprous oxide. The remains of his appliances which have been found show clearly that the metal from the smelting operation was remelted in crucibles and poured from them into moulds of clay or stone (Fig. 2), perhaps of sand, but of this there is no definite evidence. The metal was not laded from the smelting furnace, as the small crucibles with rude handles which have occasionally been found, and have been erroneously supposed to be ladles, show no signs of having been exposed to a high temperature both on the inside and outside, as would have been the case had they been so used; the interior and upper edges alone bear marks of such exposure. The reason for this will be seen later.

Implements and weapons of bronze, unlike those of copper, were always cast in closed moulds. The method of melting the metal in each case was as follows:—The furnace or hearth was merely a shallow depression in the ground. The crucibles were made of clay, which was sometimes mixed with finely cut

straw or grass. They were embedded in the ashes at the bottom of the hearth in such a manner that their faces and sides were thoroughly protected from the intense heat of the fire, their upper edges and interior only being exposed. This method had been adopted owing to the fusible character of the clay of which they were made. The fuel used was wood and the charcoal which was produced during the process. After a crucible had been thus placed and charged with copper, copper and tin-stone, or copper and tin, the fire was

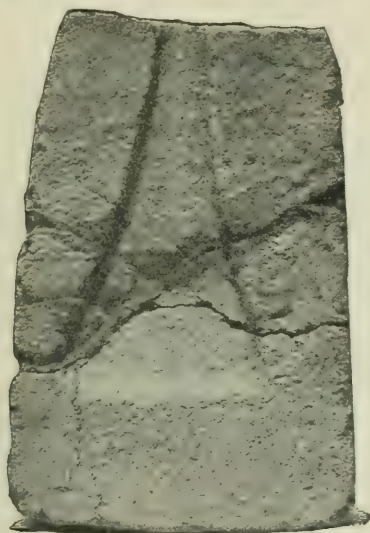


FIG. 2.—Stone Mould found at El Argar.

made up over it. A sufficiently high temperature for melting the metal could be obtained by the wind alone. When the contents of the crucible had melted, the crucible was removed from the furnace and the metal poured into a mould.

In consequence of this mode of heating, the lower parts of the crucible will, it is evident, bear but little traces of the action of a high temperature, whilst the upper edges and interior will exhibit a fused or semi-fused structure, and this is precisely what we find in all early crucibles.

Some of the most important types of crucibles are illustrated in Fig. 3.

The small capacity of by far the greater number of these crucibles which have been found is worthy of note. Few can have held more metal than would suffice for the casting of a single axe. This is, however, not surprising, if we remember that they are the appliances of that remote time when metallic weapons were only beginning to replace those of stone.

The clay vessel (No. 1) was found among the débris of pile dwellings in Carniola. It is open to doubt whether it is a crucible or not.

No. 2 is a common form widely distributed in the remains representing the early Bronze Age in the pile dwellings of Switzerland, the Danubian basin, and Ireland. It is furnished with a socket for the insertion of a stick, by which it was removed from the fire and its contents poured into a mould.

No. 3, a shallow oval dish of somewhat rare occurrence, found in the Mond See. They can hardly have been used for making castings; it is, however, just possible that they were employed in a rude refining process, by which part of the impurities in the crude copper obtained by smelting were removed by allowing the air to act on the surface of the metal; or, it may be, they are the vessels in which the founder first made his alloy, in order to test its properties, before making the actual casting of a weapon.

No. 4 was found in the remains of a crannog in Lough Mourne, Ireland.

Nos. 5, 6, 7, 8, 9 represent crucibles found at Dunadd, Argyll, together with iron spear-heads and other iron objects.

Nos. 10 and 11 were found together with copper and bronze implements and stone moulds in Mercia and Almeria, in the south-east of Spain.

The moulds used by primitive man are also of considerable interest. The earliest are of the class known as open moulds, and consist merely of cavities of the necessary form and size hollowed in the surface of a stone. Of these, Fig. 2 is a characteristic example.

Plate II. Nos. 1 to 5 represent copper celts cast in these moulds. Similar moulds of clay were also used, but owing to their perishability few have been found.

The moulds of the later Bronze Age were either of clay or

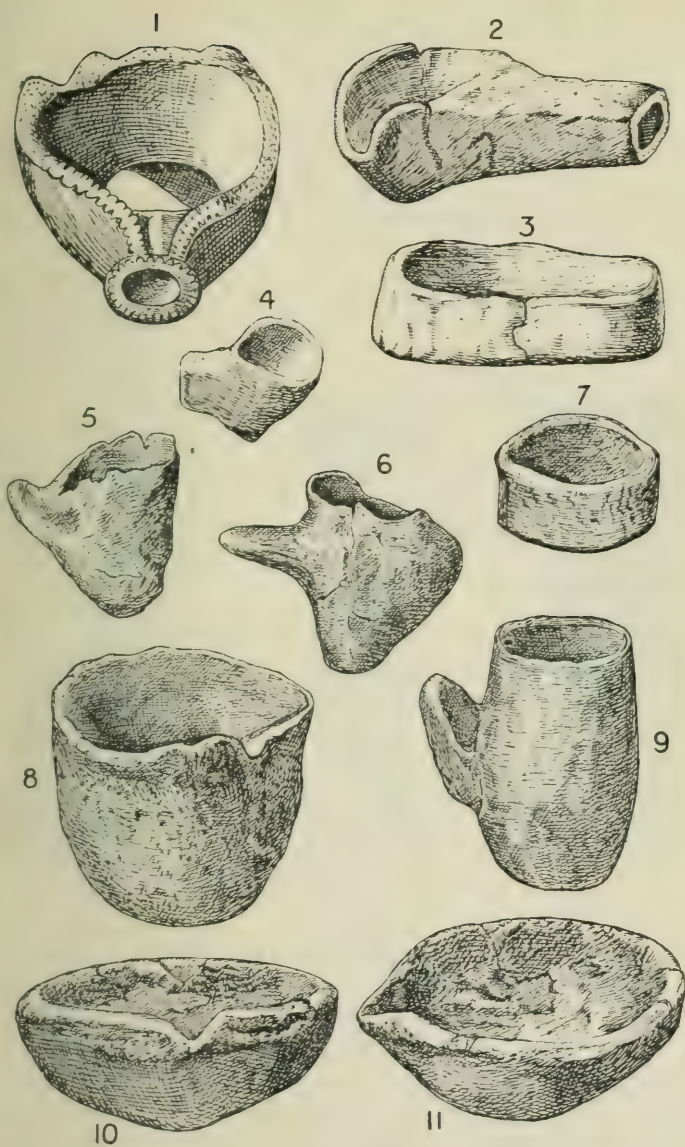


FIG. 3.—Prehistoric Crucibles.

bronze. An excellent example of one of bronze is shown in Fig. 4. It was used with a core, and differs but little from moulds of the present day.

In casting swords and daggers of bronze the moulds must have been of clay and been heated to dull redness at the time when the metal was poured in—a method of casting which is still practised in Japan, and which I described in my May lecture—as by no other means could such perfect castings of



FIG. 4. —Bronze Mould and Cast.

their thin blades have been obtained. The castings generally were hammered at the cutting edges, and it is to this hammering, and to it only, that the hardness of the cutting edges of both copper and bronze weapons is due, and not to any method of tempering. Much has been written about the so-called art of tempering bronze, supposed to have been practised by the men of the Bronze Age in the manufacture of their weapons; the hardness is also said to be greater than can be given to bronze at the present day. I should like to correct

this error, as it can only have arisen owing to its authors never having made any comparative practical tests of the hardness of bronze. Had they done so, they would have found that the ordinary bronze of to-day can be made as hard as any, in fact harder than most, of prehistoric times, by simple hammering alone.

We will now pass to the consideration of the copper alloys of Mycenæan, Babylonian, Greek, and Roman times. Until the introduction of iron, copper and bronze played an important part in the lives and struggles of the early races occupying the Greek peninsula and its islands, whilst in later times the alloy bronze afforded an imperishable material to the great sculptors of the golden age of Greece, by which many of their incomparable works have been preserved to us.

In Greek literature we have no records of metallurgical processes relating to copper or its alloys, such as are to be found in the writings of Roman authors, notably Pliny.

Strabo, the only Greek author who condescends to take any notice of metallurgy or metal working, confines his statements to gold, silver, and lead. But at Laurion the remains of ancient furnaces for smelting lead ores, which have been unearthed from time to time, indicate that low hearths resembling those of the Bronze Age were extensively employed; and if we may reason from Japanese metallurgical procedure, similar furnaces would be used for copper. The island of Cyprus, once rich in copper ores, was doubtless the source whence the inhabitants of the Greek peninsula in early times obtained their copper.

Among the earliest specimens of the metal which have been found in Greece are some copper nails which were obtained by Dr. Schliemann at Orchomenos, a city in Bœotia, which was in a state of decay in the time of Homer. They belong to that remote period in Mediterranean civilisation to which the name Mycenæan has been applied.

One of these analysed by Rammelsberg had the following composition:—

Copper, per Cent.	Lead, per Cent.	Iron, per Cent.
99.53	0.27	0.20

Two very large nails of about the same date, one weighing $2\frac{1}{2}$ lbs., which were found by Schliemann with some carbonised beams in his excavations in the second city on the site of Troy, were analysed by Schröter with the following results:—

Copper, per Cent.	Iron, per Cent.	Tin, per Cent.
99·55	...	...
98·65	0·85	0·45

They are interesting as showing that the men of that remote period were able to produce copper of tolerable purity, but this would not be difficult, as the ores which they worked would be oxidised ores, oxides, and carbonates from the outcrops of veins, viz. the parts which were exposed at the surface of the ground.

Bronze was also then in use for nails and cramps in building construction, but especially for weapons, and was of good quality, one of the weapons consisting of copper, 90·76 per cent.; tin, 8·42 per cent.; lead, 0·32 per cent.; iron, 0·54 per cent.

There is abundant evidence to show that Egypt was the first in the field in artistic bronze casting. When it first began it is difficult to say, but objects of at least as early as 3000 B.C. are in existence.

Even in the early examples great technical skill is displayed. The most ancient Greek bronzes are solid castings, whereas in Egypt they are light and hollow, having been cast with a core of argillaceous sand, which still remains in many specimens.

	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Zinc, per Cent.	Nickel, per Cent.	Antimony, per Cent.	Arsenic, per Cent.	
Ancient statuette with core inside	85·06	2·75	10·89	0·71	...	0·40	0·37	...	Fellenberg.
Fragment of a great statue	81·22	2·51	16·00	Trace	...	0·25	0·02	...	Bibra.
Statuette Osiris (300 to 200 B.C.), with core	76·83	11·23	11·70	Trace	...	...	0·13	0·11	..
Plate from a mummy case (300 to 200 B.C.)	75·24	13·15	11·40	Trace	...	0·21	...	...	..

The statuary bronze frequently contains considerable amounts of lead, sometimes with but little tin, and the question naturally suggests itself, whether this arose from scarcity of the latter metal. Only a few analyses have been made, and unfortunately few of the objects can have even approximate dates assigned to them.

Bronze was in extensive use in Nineveh about 1000 B.C. for vessels and utensils of many kinds, and curiously was sometimes employed for those which we should now make of more precious metals.

In the British Museum there is a large collection of these objects which were obtained by Layard in his excavations in the ruined city.

Several have been analysed by Fellenberg, of which the following are representative:—

	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Antimony, per Cent.	Arsenic, per Cent.	Nickel, per Cent.
Small rod . .	86·84	12·70	0·28	Trace	...	...	0·18
„ cup . .	80·84	18·37	0·43	0·16	...	...	0·20

In three other articles analysed by Phillips in Dr. Percy's laboratory the tin ranged from 9·8 to 11·33 per cent. All the above are true copper-tin bronzes with only traces of lead.

In one of the objects analysed by Phillips, one of the feet of a tripod, the bronze had been cast over an iron core. This appears to have been a common practice in Nineveh for rods, handles, &c., not because iron was cheaper than bronze, but for constructional reasons, the iron being relied on to give strength, whilst the bronze was pleasing to the eye, and could be easily decorated.

The bells found have 14 per cent. of tin, showing that the Assyrians were well aware of the effect produced by changing the proportions of the metals.

The Greek copper alloys of a later period, many examples of which are found in the coins of about the fourth century B.C., are true bronzes consisting of copper and tin, with lead or zinc only as impurities and not intentionally added.

A curious feature in them is the presence of nickel varying from traces up to 0·5 per cent. The percentage of tin is

somewhat irregular, but in most examples ranges from about 8 to 11 per cent. The same is true of the Macedonian coin-age alloys from the third to the second century B.C., but the percentage of tin in them is somewhat greater, generally being from about 10 to 12 per cent. These alloys were undoubtedly made by melting together the metals copper and tin, and not, as in the Bronze Age, by smelting stanniferous copper ores, or by melting copper with tin ore.

The Macedonian alloys more particularly, as will be seen from the following analyses of typical coins by Bibra, are the best of the ancient bronzes:—

Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Antimony, per Cent.	Nickel, per Cent.	Sulphur, per Cent.
87·72	11·70	Trace	0·27	Trace	0·38	...
88·56	10·31	0·73	Trace	Nil	0·40	Trace.

A little later in Greek coins we find lead as an intentional constituent in various proportions, ranging generally from about 6 to 10 per cent., or even more, with a proportionate reduction in the percentage of tin. The Macedonian coins, however, with few exceptions, preserve their character as true bronzes.

The alloys used for statues are frequently true bronze with 9 to 11 per cent. of tin, but in other examples about 5 per cent. of lead has been added, probably with the intention of increasing the fusibility of the alloy and its fluidity when molten.

The statements of Pliny as to the composition and mode of manufacture of the bronzes as imitated in Rome throw but little or no light on the subject; in fact they are for the most part useless and misleading. As regards the Corinthian bronze, the beauty of which is so extolled by classical writers, he states that the alloy was discovered by the Romans at the sack of Corinth, when vessels of gold, silver, and bronze had been accidentally melted together during the burning of the city and produced a golden bronze.

The siege of Corinth, however, occurred in 146 B.C., but the excellence of Corinthian bronze had been recognised long before.

Whatever may have been the exact composition of this

bronze, of which several statues are said to have been cast, I may say that no addition of gold or silver to any copper-tin alloy will cause it to closely resemble gold. Imagination must, I think, be responsible for the accounts given of this bronze by ancient authors, especially when we read also that its beauty was derived from being cooled in the water of the fountain of Peirene.

Unfortunately but few analyses have been made of Greek bronzes. The following are the only representative analyses I can find:—

	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Zinc, per Cent.	Iron, per Cent.	Nickel, per Cent.	Sulphur, per Cent.	
1. Statue in the Art Museum, Dorpat }	88.54	11.46	...	...	...	...	...	Gobel.
2. Statuette	88.51	10.13	...	...	1.02	0.34	Trace	Bibra.
3. "	80.91	10.13	5.25	0.31	...	0.12	"	"
4. "	89.96	9.22	...	...	0.44	0.38	...	"
Fragment of dra- perry, fifth century B.C. }	84.49	9.47	5.31	...	Trace	...	...	Wingham.
Statue of Dionysus, Græco - Roman period }	85.05	10.35	4.65	...	Trace	...	...	"
Statue from Ephe- sus, fourth century B.C. }	89.04	6.09	4.87	...	...	...	...	Natterer.
Vase, 336 to 324 B.C.	81.76	10.90	5.25	...	0.15	Cobalt 1.22	...	Flight.
Bowl from Roman settlement in Nubia }	80.81	13.08	5.14	...	0.29	Ni & Co 0.46	...	Gowland.

With the fall of Greece and the rise of the supremacy of Rome we enter an important period in the history of copper and its alloys. In Spain and in Britain we find copper smelting being vigorously carried on by the Romans, and in Rome and the chief seats of the empire a further extension of the use of bronze, not only for statues and other objects of art, but for vessels of all kinds, furniture, and other articles of domestic life. Of special importance is the invention of a new alloy, brass, which comes into use for the first time in Europe.

Among the varied remains which are representative of the

Roman occupation of Britain, few are of greater interest to the metallurgist than the cakes of copper found in North Wales and Anglesea. A typical example of one of these cakes, now in the British Museum, is shown in Plate III. Its weight is 26 lbs. 12 ozs. Another, found near the old mines at Llandudno, is stamped with the words "Socio Roma," meaning "to my partner at Rome." These cakes afford us, in their form and character, unmistakable evidence of their history. They had been obtained by smelting sulphide ores, or ores containing sulphides, in low hearths, in which they had almost certainly been allowed to solidify before removal. According to Pliny, who seems in this matter to have had access to fairly trustworthy sources of information, the copper obtained by smelting was brittle and useless, and in order to obtain malleable metal from it, it was mixed with lead and melted several times, and the oftener the operation was repeated the better was the quality of the copper. This brief account of copper-refining by a non-technical writer gives us an excellent *résumé* of the process as practised in Roman times. The operation was evidently conducted with free access of air, and the lead used would, by its oxidation, aid greatly in the removal of impurities from the copper. That the process was a fairly successful one is shown by the following analyses of some of the copper coins of the empire, although from the skill displayed by the Romans in other metallurgical work we might have expected better results:—

	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Nickel, per Cent.	Arsenic, per Cent.	Antimony, per Cent.
Copper coins, Caligula, } 37 to 41 A.D. . . . }	99·24	0·10	0·46	0·20	Trace	...	...
Copper coins, Vespasian, } 60 to 79 A.D. . . . }	99·53	...	...	0·27	0·20	0·20	...
Copper coins, Vespasian, } 60 to 79 A.D. . . . }	99·13	0·22	Trace	Trace	0·33	...	0·32

The earliest Roman alloys which have come down to us are copper, lead, tin, alloys of the fifth century B.C. Their chief peculiarity is their very large content of lead, namely, from about 19 to 25 per cent., the tin being about 7 per cent.

They were worthless for practical purposes, but formed the alloy of which the large coin of the republic—which weighed from 8 to 11 ozs.—the “As,” was cast. One of these analysed by Phillips consisted of—

Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Cobalt, per Cent.	Nickel, per Cent.	Sulphur, per Cent.
69.69	7.16	21.82	0.47	0.57	Trace	Trace

These copper-lead-tin alloys continued in use as coinage alloys until 20 B.C., but from that date until two centuries later lead is seldom found in coins except as an accidental impurity.

The large percentages of lead were undoubtedly added in these cases on account of the cheapness of the metal as compared with that of copper and tin.

The copper-tin-lead bronzes appear also to have been used by the Romans for engineering and industrial purposes. An interesting example of this use is afforded by the broken shaft of a water-wheel, which was found in the lower Roman workings of the north lode of the Rio Tinto mine. The water-wheel was probably built in the first century of our era, as coins of the time of Vespasian (70 to 81 A.D.) were found near it. The analysis which follows was made by Henry N. Thomson,* the metallurgist of the Washoe plant, Anaconda:—

Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Arsenic, per Cent.	Antimony, per Cent.	Silver, oz. per ton.	Gold, oz. per ton.
77.3	9.2	10.5	1.1	0.5	Trace	10.2	0.2

The bronze used for statues by the Romans also always contains lead in considerable proportions, as much as 6 to 12 per cent. being often present. In this they were doubtless influenced by Greek practice, the lead being added to the bronze to increase its fusibility and more especially its fluidity when molten, so that it might receive the sharpest possible impressions of the mould.

As it might be thought that the presence of 5 per cent. of lead in bronze would seriously diminish its tenacity, I therefore determined the tenacity of a copper-tin-lead bronze composed of copper, 88.0 per cent.; tin, 7.0 per cent.; lead, 5.0 per cent., and found that it was only 1 ton per square inch lower than that of a copper-tin alloy consisting of nine parts of

* *Engineering and Mining Journal*, August 22, 1908.

copper and one part of tin. The large percentages which occur in some Roman statues must, however, have resulted in weakness and comparative brittleness.

I may point out here that the addition of lead to bronze was and is largely practised by the Japanese, not only for the reasons stated above, but also to enable the objects cast of the alloy to receive a rich brown patina when suitably treated; and in this connection it is worthy of note that Pliny states that by the addition of lead to Cyprian copper, the purple tint is produced that we see in the drapery of statues.

But few analyses have been made of Roman statues, notwithstanding the vast number now in the chief museums of Europe. The following are characteristic:—

	Copper, per Cent.	Tin, per Cent.	Lead, per Cent.	Iron, per Cent.	Zinc, per Cent.	Nickel, per Cent.	Antimony, per Cent.	
Colossal statue . . .	78.33	10.77	10.24	0.14	...	0.52	...	Fellenberg.
Statuette . . .	78.77	9.03	12.07	0.13	...	Trace	...	Bibra.
" . . .	87.36	6.23	6.20	Trace	Trace	0.21	...	"
Apollo, Gallo-Roman, } first century A.D. }	80.70	6.44	9.97	Trace	Trace	...	...	Wingham.

The alloy used by the Romans for mirrors does not differ greatly from that in use in Europe for metallic mirrors in comparatively recent times, the percentage of tin ranging from 23 to 28 per cent., but lead is present in all from about 5 to 7 per cent.

COPPER-ZINC ALLOYS—THE BRASSES.

Zinc as a distinct metal was unknown in early times, in fact as late as the sixteenth century it was not known in Europe; but there are strong reasons for the belief that the Chinese were acquainted with it as metal at least several centuries earlier. It is occasionally but rarely present in the implements and weapons of the Bronze Age, and then only in small quantities as an accidental impurity, which has been derived from smelting copper ores containing it.

In somewhat later times it occurs in rings, armlets, and

other personal ornaments found in the ancient burial mounds of Germany and Denmark, but these mounds are of post-Roman date, and the objects mentioned have really been made from Roman coins.

In Greek alloys zinc is never found as an intentional addition but only as an impurity, about 1 to 2 per cent. or less; in fact, according to Gobel, all antique objects which contain zinc are not Greek; but this, in my opinion, is only true for those containing considerable proportions of the metal, and not for those with the small amounts just mentioned.

In Roman times it first appears in the coins of the Republic as an impurity; as an intentional addition, however, it only begins in the time of Augustus (20 B.C. to 14 A.D.), when brass was made for the first time in the world's history.

One of the earliest examples is a coin of 20 B.C., which contains 17.31 per cent. of zinc.

The Romans were the first makers of brass. Although they were unacquainted with the essential constituent zinc, yet they had discovered that by melting copper together with a certain ore (calamine), a yellow alloy of a more golden colour than bronze could be obtained.

It was first employed for coins which appear to have had a higher value than those of bronze, even up to the time of Diocletian (286 to 305 A.D.), when six parts of brass are said to have been worth eight parts of copper. There is, too, a curious statement by Procopius in his *De Edificiis* relating to its value in the fifth century A.D., in which he says that brass was then not very greatly inferior to silver.

The method employed by the Romans in making this alloy from copper and calamine was a very simple one.

It was conducted as follows:—The calamine was ground and mixed in suitable proportions with charcoal and copper in granules or small fragments. This mixture was placed in a crucible, and was very carefully heated for some time to a temperature sufficient to reduce the zinc in the ore to the metallic state, but not to melt the copper. The zinc being volatile, its vapour permeated the fragments of copper, converting them into brass. The temperature was then raised,

when the brass melted, and was poured out of the crucible into moulds.

This process was so effective that, until a comparatively recent period, all brass was made in Europe by the ancient process, and even until a few years before 1861 it was thus made at Pemberton's Works in Birmingham. It was called "calamine brass," and was generally believed to be superior in mechanical properties to brass made by using metallic zinc.

The survival of this ancient process affords a striking example of the conservatism characteristic of British metallurgy, as brass had been made in England by Emerson, using metallic zinc, in 1781. This, so far as I have been able to ascertain, was the first to be made in Europe by melting copper and zinc together.

In Roman alloys the percentage of zinc was very variable, ranging from about 11 to 28 per cent. For ornamental purposes and scale armour they had an excellent alloy, of which the following are examples. Several rosettes and studs which had formed the mounts of a casket were unearthed in the excavations at the Roman city of Silchester in 1900.

The rich golden colour of these rosettes and their extreme thinness was so remarkable that I made the following analysis of one of them and its central stud:—

	Brass Rosette, per Cent.	Brass Stud, per Cent.
Copper	80·42	82·31
Zinc	18·77	17·11
Lead	0·09	0·08
Iron	0·62	0·45
Silver	Trace	Trace
Nickel and Cobalt	Nil	Nil
Tin	Nil	Nil
	99·90	99·95

Both the rosette and stud are of practically the same alloy. Now, of all the copper-zinc alloys, those which contain from 15 to 20 per cent. of zinc possess the greatest ductility.

This Roman brass is therefore one of the most ductile of the whole series of brasses. It is, besides, identical in com-

position with Tournay's alloy (copper, 82·5 per cent.; zinc, 17·5 per cent.), which, on account of this property and its rich colour, is used for the manufacture of all French jewellery made from thin sheets in imitation of gold. Hence the brass of which the rosettes are made is notably of the composition which is best fitted for making such ornaments, and is that which would be employed at the present day.

I have also examined the scales forming part of a suit of Roman scale armour dug up in the excavations of a Roman camp near Melrose, and found them to be of practically the same composition as the above.

The following analyses represent selected examples of Roman brass containing the maximum amounts of zinc:—

Analyses of Roman Brass.

Coins.	Copper, per Cent.	Tin, per Cent.	Zinc, per Cent.	Lead, per Cent.	Iron, per Cent.	Antimony, per Cent.	Arsenic, per Cent.	Nickel, per Cent.	
1. Augustus, 30 B.C. to 14 A.D.	87·05	0·72	11·80	Trace	0·43	Trace	Trace	Trace	Bibra.
2. Tiberius, 41 to 54 A.D.	72·20	...	27·70	...	...	...	...	...	Gobel.
3. Nero, 54 to 68 A.D.	77·44	0·30	21·50	Trace	0·32	0·20	...	0·24	Bibra.
4. Vespasian, 71 A.D.	81·97	...	18·68	0·14	0·12	...	...	...	Phillips.
5. Trajan, 98 to 107 A.D.	77·59	0·39	20·70	...	0·27	...	...	...	Tookey.
6. Sabina, wife of Hadrian, 100 to 137 A.D.	82·35	0·43	16·84	Trace	0·38	Trace	Trace	Trace	„
Other objects:— Fibula found at Mayence	75·07	0·20	24·45	...	0·28	...	...	...	Fellenberg.
7. Armlet	82·01	1·79	15·30	0·80	Trace	Trace	...	0·10	Bibra.
8. Fibula	84·45	1·72	12·31	1·44	0·08	...	...	Trace	„
9. Needle, Ireland	84·27	2·36	14·70	...	...	...	...	...	Church.

The greater number of the Roman coins contained less zinc than any of the above, whilst No. 2 has the highest percentage in any analysis I can find. The chief use of brass by the Romans, apart from the various coinages, appears to have been for fibulæ and other personal ornaments and for decorative metal-work, and for these, as we have already seen, they had invented a metal perfectly suitable both as to its workable qualities and its beauty.

That they were the first inventors of brass is, I think, without doubt, as the alloy is not found in Greece or the Greek colonies or elsewhere until the time of the Roman Empire.

In the eleventh century great care was bestowed on the purification of the copper intended to be used in the manufacture of calamine brass for objects of art, more especially for the removal of lead, as it had been found that brass contaminated with that metal could not be satisfactorily gilt.

For an account of the process, which seems to have been conducted on but a small scale, we are indebted to a manuscript written by Rugerus Theophilus, a monk who lived in the early part of that century. The following is a translation by Hendrie :*

"Of the Purification of Copper.—Take an iron dish of the size you wish, and line it inside and out with clay, strongly beaten and mixed, and it is carefully dried. Then place it before a forge upon the coals, so that when the bellows act upon it the wind may issue partly within and partly above it, and not below it. And very small coals being placed round it, place the copper in it equally, and add over it a heap of coals. When, by blowing a long time, this has become melted, uncover it and cast immediately fine ashes of coals over it, and stir it with a thin and dry piece of wood, as if mixing it, and you will directly see the burnt lead adhere to these like a glue. Which being cast out, again superpose coals, and blowing for a long time, as at first, again uncover it, and then do as you did before. You do this until at length by cooking it you can withdraw the lead entirely. Then pour it into the mould which you have prepared for this, and you will thus prove if it be pure. Hold it with the pincers, glowing as it is, before it has become cold, and strike it with a large hammer strongly over the anvil, and if it be broken or split, you must liquefy it anew as before. If, however, it should remain sound, you will cool it in water, and you cook other (copper) in the same manner."

From this, therefore, we may presume that as far as the

* *An Essay upon Various Arts.* In three books. By Theophilus. Translated by Robert Hendrie. John Murray. London, 1847. Page 313.

copper was concerned the calamine brass of that period intended for art work would be a very pure alloy.

As regards the brass which was made in this country by the ancient method, *i.e.* "calamine brass," and that made with spelter, the former, according to Dr. Percy, was preferred for the manufacture of buttons and articles to be gilt, as it was said to take the gold better in "water-gilding." It was also preferred for other purposes. It is difficult to see why there should be any difference between the two brasses unless the spelter of those days was more impure than at present, possibly containing more lead and iron. Prejudice against the metal made by a new process may, however, have been one of the causes of the opposition which was raised to its use.

It may be of interest if we now consider briefly the composition of calamine brass in this country and Europe up to the middle of the seventeenth century, as shown by the following examples which admit of a correct date being assigned to them:—

	Copper, per Cent.	Tin, per Cent.	Zinc, per Cent.	Lead, per Cent.	Iron, per Cent.	Nickel, per Cent.	Antimony, per Cent.	
1. Statue at Munich, } 1600 A.D.	76.90	0.64	19.69	2.68	0.17	0.10	...	Hampe.
2. Bas-relief, Ger- } many, beginning of 17th century	65.34	5.04	25.64	2.09	1.79	0.10	...	Bibra.
3. Memorial brass, } England,* 14th century	66.64	Trace	23.27	...	0.08	...	...	...
4. Memorial brass, } England, 1456 A.D.	67.54	1.16	24.16	7.14	..	...	...	Gowland.
5. Memorial brass, } England, 1470 A.D.	66.81	2.56	28.50	2.13	...	...	...	..
6. Memorial brass, } England,* 1504 A.D.	64.00	3.00	29.5	3.50	...	...	...	...
Angel's head, 17th } century, Germany	59.35	1.30	37.63	Trace	1.13	0.39	0.20	Bibra.

Unfortunately one example alone, No. 3 in the table, is free from an excess of impurities or intentional additions, and with this exception none throws any light on the causes of the superiority attributed to calamine brass as compared with

* Haines' *Manual of Monumental Brasses*.

that made by the direct union of the metals copper and zinc.

The alloy termed "latten," of which the memorial brasses Nos. 3, 4, 5, and 6 were cast, is as variable in composition as the ancient brasses, owing probably to the idiosyncrasies of separate founders as regards the mixture of metals best suited for this purpose, especially the proportions of tin and lead to be added.

With the disappearance of the calamine brass, one of the last links in the chain connecting the modern metallurgy of copper and its alloys with antiquity is broken. An important link, however, still remains in the *cire perdue* process of casting bronze, a process in which it can hardly be said that we are any further advanced than the Greek founders of some centuries before our era.

Further, it must not be overlooked that the principles on which copper refining is based were carried out in practice in the time of Pliny.

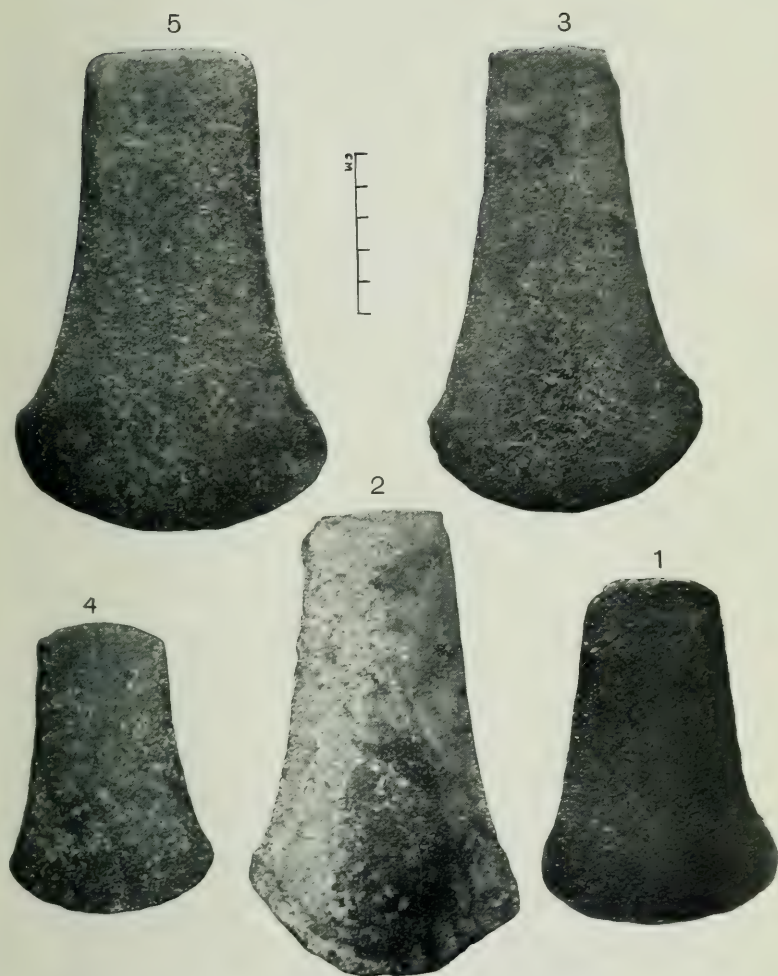
I hope that the outline of the history of copper and its alloys which I have endeavoured to place before you—I fear imperfectly—may not be without value in these practical days.

The influence of copper, and particularly of bronze, from the Age of Bronze to that of Imperial Rome, is an element which has played a greater part in the civilisation of Europe than that of any other metal. This is often lost sight of in this age of iron and steel. It hence seemed to me that it might be of interest and possibly of profit to present to the members of our Institute an account of the achievements which our fellow-workers in bygone ages were able to accomplish without the elaborate appliances and scientific knowledge of our own times.

PLATE I



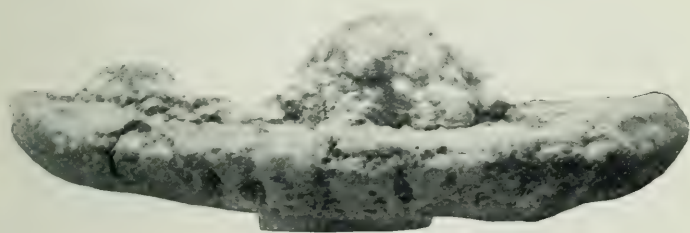
Bronze Flat Axes. (British Museum.)



Copper Celts. (British Museum.)



PLATE III



Roman Cake of Copper. Found at Amlwch, Anglesea.
(British Museum.)

APPENDIX.

Experimental smelting of mixed copper and tin ore in the primitive furnace (Fig. 1). The charge consisted of:—

	Lbs.
Copper ore (copper carbonate) containing 30 per cent. copper	15
Tin ore (cassiterite) containing 29 per cent. tin	10
Limestone	7½
Charcoal	10

The charcoal and limestone were coarsely ground and mixed with the ores.

The furnace cavity was filled with charcoal, which was also piled above it to a height of about 2 or 3 inches. When the charcoal was well alight, a layer of the charge was spread over its surface, then another layer of charcoal, then alternate layers of the charge and of charcoal were added so as to form a conical heap. A gentle blast was then started through a 1-inch blast-pipe, and when the charge began to sink down into the furnace cavity it was slightly increased. When the whole of the charge and fuel had sunk down into the furnace the blast was stopped, the slag and remaining fuel removed, and the metal allowed to solidify. The metal was analysed and found to contain 22·0 per cent. of tin.

[For permission to publish in the *Journal* Figs. 1 and 2 the thanks of the Institute are due to the Royal Anthropological Institute, and to the Society of Antiquaries for Fig. 4.—Ed.]

CONTRIBUTIONS TO THE HISTORY OF CORROSION.*

PART I.

THE CORROSION OF CONDENSER TUBES BY CONTACT WITH ELECTRO-NEGATIVE SUBSTANCES.

BY ARNOLD PHILIP, B.Sc., A.M.I.E.E., Assoc.R.S.M.
(ADMIRALTY CHEMIST).

ALL condenser tubes through or round which sea water flows are corroded, but the nature of this corrosion varies very greatly. By far the greater number of such tubes are merely uniformly corroded over as much of their surface as is exposed to salt water. It is not, however, with cases of corrosion of this uniform character that it is proposed to deal here. A certain small number of tubes, besides the uniform corrosion of their surface on the sea-water side, also undergo a local corrosion or pitting. The general uniform surface corrosion, although doubtless undesirable, is comparatively harmless. It is the local corrosion or pitting which is the cause of trouble to the engineer. The following remarks must be understood as applying specially to the relatively small number of cases in which localised corrosion occurs in condenser tubes made of Admiralty composition, namely, copper 70, tin 1, and zinc 29 parts per cent.

Within the last eighteen months, owing to the fact that the Corrosion Committee of this Institute decided to examine as a first step in their investigations the question of the corrosion of condenser tubes by sea water, a good deal more attention has been given to this particular form of corrosion by the general technical public than had previously been the case. Nevertheless, it must not be forgotten that a very considerable amount of knowledge had already been accumulated by those whose duty it had been to deal practically with

* Read at Annual General Meeting, London, January 17, 1912.

machinery involving the use of sea-water condensers, and it is the author's opinion that the cause for fully 90 per cent. of the cases of corrosion observed in the establishments of the Royal Navy has long been known, and the methods of overcoming or neutralising such corrosive action have also been experimented with, and that very effective protective devices have been employed for a long time back. It is, however, conceivable that more satisfactory preventive methods may be devised in the future, and it is to this end that the investigations of the Corrosion Committee will no doubt be largely directed.

In the author's opinion, then, the main problems which remain to be solved concerning localised condenser-tube corrosion are, firstly, the explanation of the cause of rather less than 10 per cent. of the small number of cases which are now observed; and, secondly, the device of a general means of preventing these and all other cases of corrosion superior to the method of protector bars, &c., of zinc, aluminium, steel, or iron, as at present employed.

The 10 per cent. of the total cases of observed corrosion referred to above is considered to be rather an excessive estimate of the number which are found to be obscure in origin, and whose occurrence cannot be readily assigned to one of the more usual causes of corrosion. There are several reasons for this opinion, and among them is the difficulty of obtaining full and reliable information concerning the natural history of the occurrence. The necessarily high pressure under which engineering duties are normally carried out renders it always difficult and sometimes impossible to fully state all the observable conditions under which a particular case of corrosion has occurred, and the omission of such details, it is considered, frequently causes such a case of corrosion to be classed as one of the 10 per cent. of obscure cases, whereas it should actually be classed amongst those whose origin is known.

It is the engineers, who are actually responsible for the efficiency and maintenance of condensers, who are able to provide the necessary information upon which an opinion can be formed as to the causes of observed cases of corrosion. In

order to secure that such information is not overlooked at the time, it is very desirable that a suitable schedule of queries should be filled in. This course was proposed by the author in the discussion on Admiral Corner's Paper* at the Annual General Meeting of the Institute held in January 1911, and he is glad to understand that this proposal is now to be actively taken up. A copy of such a schedule of queries as used in the past by the author, and as revised in February 1911, may be of some interest at the present moment, and is therefore given *in extenso*:—

“FORM OF SCHEDULE OF PARTICULARS TO BE FURNISHED WHEN THE STATE OF ANY CONDENSER IN WHICH CORROSION IS SUSPECTED IS REPORTED UPON.

“As far as possible the following particulars should be given:—

- “1. Name of ship or establishment.
- “2. Date of examination.”
- “3. Nature of cooling water (fresh, salt, or brackish).
- “4. Does cooling water flow inside or outside tubes?
- “5. Date at which tubes were first installed.
- “6. Has condenser been continuously in use?
- “7. If not continually in use, state, if possible, the approximate total periods of use and disuse.
- “8. When condenser is not in use, has it been the custom to leave the cooling water in the condenser or to drain it off?
- “9. If water is drained off, are tubes dried by steaming?
- “10. Are condenser tubes horizontal or vertical?
- “11. Nature of metal casing (iron, steel, gun-metal, &c.).
- “12. Nature of ends of casing or doors if of different material from body.
- “13. Nature of metal of tube plates.
- “14. Method of securing tubes in tube plates: are they in metallic contact?
- “15. Total number of tubes in condenser.
- “16. Total number of leaky tubes.
- “17. Length of tubes.
- “18. Thickness of walls of tubes.
- “19. If protector bars or plates are used, of what metal are they?

* *Journal of the Institute of Metals*, No. 1, 1911, vol. v. p. 125.

“ 20. How are protector bars fitted, if used ?

“ 21. Transverse and longitudinal sketch diagrams of the paths of the condenser water through the condenser should be given, and the points of entry and exit of the water in the tubes should be clearly marked, as also the points of corrosion.

“ *Note.*—When it is desired to remove faulty condenser tubes from a condenser for examination, it is desirable that before the tubes are loosened the ends shall be so marked as to show clearly which is the lower side, and also to indicate the end at which the cooling water or (steam) enters.

“ After marking and withdrawing the tubes they should, if possible, be forwarded for examination without further cutting or other mechanical damage. If it becomes necessary for the purpose of inspection or packing to cut a tube, the cutting should be carried out without the use of any lubricant.”

It may be found desirable to enlarge the above schedule after further experience has been gained in its use, and suggestions in this direction, especially such as have been arrived at as the result of practical experience, are invited.

Notwithstanding the attention which has been concentrated by the Admiralty upon the question of the corrosion of the condenser tube, it must be remarked that the actual percentage of tubes in which this localised corrosion or pitting has been observed is extremely small. In short, one of the chief difficulties in studying the behaviour of condenser tubes under corrosion is due to the fact that the corrosion so seldom appears. In spite of the fact that some millions of tubes are in use in the Royal Navy at any given moment, the number of cases, as coming under the notice of the author, in which localised corrosion has been observed do not at present amount at the most to more than about two per annum. This freedom from corrosion must, it is considered, be attributed to three causes:—Firstly, to the particular chemical composition of the metal which has been selected for the manufacture of tubes. Secondly, to the very satisfactory manner in which tube manufacturers are able to produce tubes of the exact chemical composition specified. (In this connection it may be stated that during the past ten years only one case is known

to the author in which the chemical composition of a corroded tube could in any way be considered as not satisfying the specified limits, and in that particular case the 1 per cent. of tin had been omitted from the mixture.) The third cause to which the freedom from corrosion of the condenser tubes used in H.M. service is to be attributed is undoubtedly the consistent manner in which the use of steel, iron, or zinc protector slabs and bars, &c., has always been insisted upon.

The protective action of iron and zinc in condensers in H.M. service has been made use of in several forms. It was originally used in condensers in which the body was of cast or wrought iron, and the sea water passed outside the tubes, and was therefore at the same time in direct contact with the outside of the metal condenser tubes and the inside of the iron case. Under these circumstances the protection was very complete, and whilst corrosion of the steel or iron casing took place, the corrosion of the tubes was practically unknown. A particular and remarkable case in which this protective action of a cast iron casing has been very clearly demonstrated is that described by Admiral J. T. Corner.* Steel or zinc protector slabs and bars have been used attached inside the condenser doors, or on the tube plates themselves, or some of the tubes of the condenser have been replaced by iron or steel or even zinc rods, whilst in some condensers, built about four years ago, the bodies have been of metal of a composition closely approximating to that of the tubes, and the doors have been made of iron or steel. More recently condensers have been made with steel bodies.

The presence of a so-called electro-positive protective metal such as aluminium, zinc, or iron, is not, however, alone sufficient to prevent the corrosion of the condenser tubes immersed in the same bath of sea water. It is essential that there shall be a direct electrically conducting connection between the tube and the protecting metal or metals, as well as that the protector metal and the condenser tubes shall be both immersed in the same electrolyte. It has been shown again and again that any want of a good electrical connection renders the protective action of the iron, steel, or zinc upon the condenser

* *Journal of the Institute of Metals*, No. 1, 1911, vol. v. p. 119.

tubes quite nugatory. Where, however, the contacts of the protective metal with the tubes are satisfactory, corrosion does not occur.

Some facts concerning the usual length of life of main condenser tubes in H.M. service may be of interest.

The ordinary normal length of life for the main condenser tubes of a battleship should be from ten to twelve years, and many such cases can be cited.

Taking four first-class battleships, A, B, C, and D. These ships were attached to one port from 1897 to 1906, and during that period none of the main condensers was retubed except in D. In this particular case of the ship D, the main condensers were retubed in 1903, and again in 1909, but this was a special case; the necessity for retubing was not due to corrosion, but, the tubes being slack in the diaphragm plates, the vibration gradually caused the tubes to be cut through.

In the case of the ship B, some trouble was experienced in 1899, but on fitting additional protectors this was remedied, and as far as is known the condensers have not been entirely retubed to the present date—that is, thirteen years.

The first-class twin screw armoured cruiser of over 14,000 tons denoted by E recently had her condenser tubes examined, and they were found in good condition after having been in use for eight years. They were all replaced in the condenser after examination, and it is expected that they will last at least another three to four years.

A first-class battleship F, built and put into commission four years ago, recently had her main condenser tubes drawn and examined, and these were all found in excellent preservation, with no trace of local corrosion; all the tubes were replaced.

There are, however, cases when condenser tubes have often been found to require renewal, and in certain ships it has been necessary to renew the whole or part of the tubes after two years' service, or even less. In all such cases—and they are very rare—which have come under the author's notice, the trouble which had occurred was clearly shown to be due to the unsatisfactory character of the metal connection between the tubes and the protector bars.

A further peculiarity of the small number of these cases in which corroded condenser tubes have been observed is the fact that in almost all the tubes the corrosion has occurred along the bottom of the inside of the tubes, and it is considered that this indicates that the trouble has been set up by the contact of particles of coke, carbon, or ferric oxide, or other conducting electro-negative solid materials deposited from the cooling water upon the inside bottom surfaces of the tubes setting up local galvanic action. Such action is, of course, increased when a condenser is not in use and the tubes remain full of sea water, for the particles then have time to settle out along the bottom line and give rise to the localised corrosion.

If, on the other hand, the condenser is emptied of sea water when out of use, there would again appear to be a possible source of danger of corrosion along the bottom inside surface of the tubes, owing to the fact that this portion would be longest exposed to the joint action of salt water and air.

In either method of treatment, however, it is considered that these causes of corrosion could be minimised or altogether removed if it were found to be at all feasible to employ condensers with vertical or strongly inclined tubes, and if every precaution were observed, to take up the cooling water from such positions as will give the least chance of ashes from the ash-ejector, &c., being carried into the tubes.

The following five cases of corrosion of condenser tubes are all that have come under the author's own observation during the past three years, and in only one of these—Case I.—it is not possible to ascribe the corrosion to the contact of particles of electro-negative solid conducting material.

It must be remembered that the following particulars do not apply to the whole of the Navy, but only to such cases as happened to come directly under the author's own observation ; but in this respect, as most cases in which corrosion occurs, the precise causes of which are not at once apparent, are referred to him for investigation, it is probable that his experience errs on the side of having been too largely drawn from the class of less satisfactory tubes.

CASE I.—ELECTRO-GENERATING STATION CONDENSERS.

Result of analyses of five corroded condenser tubes:—

	Per Cent.
Copper	70·95 to 71·8
Tin	0·96 to 0·98
Lead	0·32 to 0·44
Zinc	By difference.

Circulating Water.—Sea water which analysis showed to be of normal composition.

Casing.—Gun-metal.

Protectors.—Zinc bars used. It was remarked that these protectors only corroded very slowly.

Remarks.—The tubes had been drawn without any note being kept as to their position, and it could not be definitely ascertained as to whether the corrosion had occurred along the bottom inside surfaces or not.

It was considered evident that the corrosion had been due to the faulty connection between the tubes and the zinc protectors which had been very little acted upon.

CASE II.—BATTLESHIP'S CONDENSERS.

Result of the analyses of ten corroded tubes:—

	Per Cent.
Copper	69·8 to 71·2
Tin	0·92 to 1·30
Lead	0·25 to 0·30
Zinc	By difference.

Circulating Water.—Sea water.

Casing.—Gun-metal.

Protectors.—Steel plates.

Remarks.—Out of thirty-two tubes drawn at one examination, ten were partially corroded, and in nine of these the corrosion had taken place on the lower inside surface of the tubes, whilst in the remaining one it had occurred at the top. Twenty-two of the tubes examined were quite uncorroded.

CASE III.—ELECTRO-GENERATING STATION CONDENSERS.

Composition of Tubes.—Eight corroded tubes were analysed with the following results:—

	Per Cent.
Copper	70·90 to 71·05
Tin	0·95 to 1·09
Lead	0·20 to 0·33
Iron	0·05 to 0·08
Zinc	By difference.

Circulating Water.—Sea water which analysis showed to be of normal composition.

Casing.—Gun-metal.

Protectors.—Steel plates.

Remarks.—In every corroded tube the corrosion occurred along the bottom inside surface on the sea-water side. The tubes were horizontal, and the axes of the corrosion pits were in every case greatest along the length of the tubes.

The corrosion was more marked at the ends of the tubes where the cooling water entered, and was almost all within the first two-thirds of the length of the tube. Corroded tubes appeared in three out of six condensers, and the three which were free from corrosion were those that had been most constantly in use. In one of the condensers in which corroded tubes were observed, all the corroded tubes were situated in the lower half of the condenser, *i.e.* near where the cooling water entered, and most were in the very lowest tubes. In the second condenser in which corroded tubes were observed three-quarters of the corroded tubes were found in the bottom half of the condenser, and most of these were in the lowest seven rows. The cooling water used, although sea water of normal composition, was liable to contain particles of coal-dust, and it is to the action of this material that the corrosion is attributed.

CASE IV.—ELECTRO-GENERATING STATION CONDENSERS.

Composition of Tubes.—Satisfactory Admiralty composition.

Circulating Water.—Sea water which analysis showed to be of normal composition.

Casing.—Wrought iron.

Protectors.—Zinc plates.

Remarks.—The corroded tubes are distributed fairly equally over the whole of the condenser, but the corrosion in each case occurs mainly along the bottom of each tube and throughout the length of the tube.

CASE V.—TORPEDO-BOAT CONDENSER.

Composition of Tubes.—Satisfactory Admiralty composition.

Circulating Water.—Sea water.

Casing.—Cast brass.

Protectors.—Steel slabs.

Remarks.—The corrosion is most marked along the bottom inside surfaces of the tubes.

DISCUSSION.

Mr. G. D. BENGOUGH, M.A. (Liverpool), in opening the discussion on Mr. Philip's paper, said that he thought the Institute was very fortunate in persuading the author to put his opinions down in black and white for the benefit of the members, so that they were able to obtain his definite opinions on the important subject of the corrosion of condenser tubes. It was always very much easier to understand the views anybody held on a particular subject when he did definitely state his opinions, and so far the only opinion that the author had expressed was in the discussion that took place on Admiral Corner's paper. There were three or four most interesting and important points in connection with the paper to which he wished to refer, the first being the list of questions that was printed on page 52. A list of questions which had been drawn up by the Corrosion Committee of the Institute was circulated amongst the members of the Institute on the previous day. The germ of those questions was the opinion put forward by Mr. Philip in the discussion on Admiral Corner's paper. Mr. Philip's were the original suggestions upon which the Corrosion Committee's questions were drawn up. Those original suggestions were not in quite so full a form as they now appeared in the paper, and he was sure the committee very much wished they had had those particulars in front of them before drawing up the list, although he thought it would be found that the committee had pretty well covered every point. Looking at the paper as a whole he thought it was possible to come to four or five very definite conclusions as the result of the author's experience. The first of those was that, in Mr. Philip's view, the electrolytic theory of corrosion was sufficient to account for practically all the cases of corrosion with which he had met in his experience. That was a very important point, because in certain quarters that theory was not altogether received with approval. The next point was that, as far as Admiralty brass was concerned, it would appear from the paper that there were so few cases of corrosion to be explained, apart from their ordinary knowledge of the causes of corrosion, that it was almost impracticable, and in any case rather unnecessary, to investigate the matter further in connection with that particular alloy. Almost the whole tenor of the paper went to show that the percentage of cases of corrosion of Admiralty brass which were not explainable was so small that it hardly seemed worth while to attempt any further investigation of that alloy, since years might be spent in getting suitable cases for investigation, and still longer in investigating them. He did not know whether other gentlemen who had had experience of the alloy shared that view, but that, it seemed to him, was the logical deduction to be drawn from the paper.

In the very few cases which the author was unable to explain, he pointed out quite clearly that he was unable to ascertain the past history of the tubes with sufficient accuracy to say whether or not he could have explained them if he had known the conditions. It was quite

possible he might have been able to explain them from the same point of view as the others. If those views were accepted, the Admiralty alloy could be regarded as a standard alloy which was practically incorrodible under ordinary conditions, and it could be used as a standard for comparison with other and cheaper alloys.

In the mercantile marine, and in a large number of land stations, such as power stations and various other works about the country where corrosion was more frequent than it was in the navy, Admiralty tubes were not used, but tubes which were considerably cheaper in price, the Admiralty tube being an expensive tube. It would therefore seem that the principal object before the Corrosion Committee of the Institute was to try and hit on an alloy, or on a process of manufacture for an existing alloy, which should be as incorrodible as the Admiralty metal, but considerably cheaper. That seemed to him to be the logical conclusion to draw from the author's experiences in connection with corrosion. He did not know whether the author would approve of those deductions, or whether he considered that he ought not to be pinned down to them. He hoped a large number of opinions would be obtained from other people who were interested in the subject and had a wide experience of the behaviour of Admiralty brass, because if the author's views were shared by a number of other gentlemen, the action of the Corrosion Committee might have to be modified in the sense he had indicated, and it would be possible to use with confidence the Admiralty brass as a standard alloy. He desired in conclusion again to thank the author for his interesting paper.

Engineer Rear-Admiral J. T. CORNER, C.B. (London), said that he thought the author had not only written a very interesting paper on the subject of corrosion, but one which, if it did not quite complete their knowledge on the disturbing causes that engineers had been troubled with, very nearly did so. He quite agreed with Mr. Bengough in his remarks concerning the composition of the tubes. It was pretty clear from the paper that with Admiralty composition tubes, and if the proper precautions which were now known to everybody were adopted, anybody who had corrosion in his condensers had nobody but himself to blame. He remembered the time some years ago when the trouble with condenser tubes was a very serious one indeed, in fact it was an epidemic, and it was not at all unusual for ships, after a few months in some cases, to have a large number of their tubes corroded and put out of action. Mr. Philip stated in his paper that there were now very few cases in his experience which he was unable to account for; and he (the speaker) felt pretty sure that after a short experience had been obtained in regard to the returns received in answer to the Corrosion Committee's questions as to the details of different tubes which had corroded, the condenser tube trouble would be almost entirely gone.

He felt very grateful to the author for the way in which he had put the paper together, taking a great interest in the question, as he had always done. Everything was so clearly stated in the paper that there was really nothing to criticise.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), said that there seemed to be just one thing lacking in the information given. He therefore desired to ask whether the author had received particulars of the form of the corrosion assumed from other members of the service who supplied data to himself. For instance, it would be interesting to know whether the corrosion had been streaky, or pitted, or otherwise. The tendency of that class of corrosion in Admiralty tubes appeared to be along the bottom surface, in and out, where the sea water was concentrated, generally when the condensers were empty. The drip along the tubes evaporated, giving an electrolyte of a considerably greater strength than would otherwise be the case were the cooling water of the same composition throughout the time the condenser was at rest.

Mr. ARNOLD PHILIP informed Mr. Vaughan Hughes that the corrosion was only inside the tube, and not outside.

Mr. VAUGHAN HUGHES said that although that statement helped him a little, it left the position in a somewhat similar state, because the concentration of the electrolyte proceeded along an area where it was likely to be evaporated. The electrolytic theory of corrosion, as stated by Mr. Bengough, seemed to explain the remarks the author had made with regard to the presence of coal and ash dust. He trusted that the author, in acquiring the information he was now insisting upon, would obtain precise particulars from those who dismantled tubes, as to the exact shape of the areas of corrosion—for example, whether streaks, pits, or other forms. At present he could not help thinking that the paper subsequently to be read by Professor Carpenter had some bearing on the matter, because it occurred to him that, according to the author, it took ten years to effect certain changes in the constituents of naval brass which Professor Carpenter had been able to obtain in two or three months. If corrosive action followed or depended on an alteration in the constituents of the tubes, with time, it would be very instructive to fathom such a supposition by a microscopic investigation of the defective tubes.

Mr. A. E. SEATON, Member of Council, said he had read the paper with a considerable amount of interest, and in doing so one or two points had struck him very forcibly. First, there were now almost no complaints of condenser tubes in His Majesty's service so long as the small amount of tin was present in the mixture: second, the statement of the author regarding tubes when vertical. That made him reflect on the instances he had quoted regarding the durability of brass tubes. When he came to think over the matter, he remembered that in the cases he had alluded to the tubes were almost invariably placed vertically in condensers. He thought, therefore, that what the author had said with regard to drainage and so on was important; in fact there should be no deposit of any kind either on the inside or outside of the tubes. It also occurred to him that the tubes in the condenser at Grimsby,

which he had stated to have suffered so very badly, were exposed to circulating water drawn from a part of the dock near the coal tips; probably it was due to the presence of coal dust in the water that the effect on the tubes had been so serious. One thing that must not be overlooked is, that in the navy the greatest care was taken to protect the tubes from galvanic action by means of zinc and otherwise. Admiral Corner alluded last year to the fact that in a certain ship with a bare iron condenser shell the tubes had lasted a very considerable time, but afterwards, when that shell was protected with a varnish paint, the tubes suffered very considerably. It would also be remembered that Admiral Corner referred to the protection that was afforded to the tubes by the presence of even a bolt or bar of wrought iron. He understood that lately, when dependence had been placed almost entirely on the iron of a condenser on the water side to protect the tubes, the loss of iron had been very severe—*i.e.* the deleterious galvanic action on the iron had been rather worse than had been before on the brass; it was a case of robbing Peter to pay Paul, or rather of robbing Peter to protect Paul. He did not know whether the author could give any information on these cases, for it was only a little hearsay evidence that had been brought to his knowledge. Engineers seemed to have got a little nearer home on the condenser tube question, and he believed the line taken up of tracing causes, rather than worrying about effects, would help the Corrosion Committee very largely in the investigations they had undertaken. He had hopes of very great things coming from them, so that in a short time members would not only know the causes, as they now knew the effects, of corrosion of brass tubes, but that the whole question would become historic, a thing of the past, and engineers would no longer suffer loss. There was, he believed, every prospect of that hope being fulfilled. A contribution such as the author's helped all the members to avoid doing wrong things, and, what is most important, to think clearly on the subject, as being the best way to carry them more than half-way towards a successful issue to this problem, as of most problems.

Mr. F. A. ANDERSON, B.Sc. (Newcastle-on-Tyne), said that the paper was an excellent example of the kind of paper read at the Institute which was calculated to prove a most useful discussion. His own interest in the subject was mainly in the direction of the prevention of corrosion, in which he had had considerable experience. The author stated on page 51 that one of the desiderata to be discovered was the device of a general means of preventing cases of corrosion. He thought himself that it would end in some method of applying electrical currents, in fact he was at work on that particular point at the present moment. He was quite astonished that the number of cases of corrosion reported had been so few in the navy, because he had a very large number of cases brought to his notice. For instance, he found by looking back, that in the last three months something like sixty to seventy cases of corrosion had come before him. A large number of those cases occurred in connection with

power stations and the mercantile marine, but quite an appreciable number of the tubes affected had been described as of "Admiralty mixture." He did not quite know what an "Admiralty mixture" tube was, generally speaking, although he quite understood what an Admiralty tube was intended to be. When a user of condenser tubes described his tubes as being of Admiralty mixture, he did not know whether he was to be understood as meaning that they were precisely the tubes that the author referred to in his paper as being in use in the navy, and that was a point he would like some enlightenment upon. In his own experience he had made no difference in his way of looking at a case whether a tube was described as being made of Admiralty mixture or not. He would not say the tube was just as liable to fail, but it caused no surprise when an Admiralty mixture tube was described as having failed. With regard to the question of the protection of tubes by electro-positive metals, he fully endorsed the view that no matter what electro-positive metal was used it was absolutely essential that it should be in proper electrical contact with the tubes to be protected. He desired to ask the author whether in the navy any special means were employed to ensure electrical contact between the tubes and the tube plates in the condensers. In the system with which he personally was concerned, special arrangements were made for ensuring electrical contact by putting a soft metal grummet between the tube and the tube plate in the stuffing-box, which was screwed up tight so that every tube was actually in known electrical contact with the tube plate, and was tested as being so. Another point in connection with the protection by electro-positive metals was that it would be of considerable interest if the author could state whether any particulars had been obtained of the current actually generated and passed on to the tubes by the metals employed. He had been making some investigations lately in regard to that point. He had recently been watching the behaviour of protective blocks of the material made by his firm in a condenser which had been so arranged that the current generated could be measured, and it had been found that the current generated per block had ranged from about half an ampere to as much as $1\frac{1}{4}$ ampere, and the general average protective current in the whole condenser had been at the rate of something like 1 ampere per 1000 square feet of tube surface. He thought those quantitative results were of considerable importance. Passing on to the question of the position of the pits in the tubes, so far as his experience went, it had been found that the pits might occur in any position, and that it was rather an exception to find them localised in any one latitude of the tube. At the same time that did not preclude the idea that specks of electro-negative material might have stuck on the inside of the tube, not necessarily on the bottom. It was a very common thing to find that an attacked tube was coated all over the inside with oxide of iron, although it was only pitted in a few places. Another remark he desired to make was with regard to the position of the ash ejector, a point which had been mentioned by a previous speaker. He had within his own experience some striking evidence of the effect of the ash ejector being placed in the wrong position. The steamer in question suffered very badly from corrosion on account of the ash ejector being

placed in front of the intake water tube. The corrosion ceased on shifting the position of the ash ejector to another place. Previously the tubes were continually being choked with ashes, and corroding. The last point to which he wished to refer was the effect of stray currents, which had a very great influence on various structures. It seemed to him that stray currents were extremely difficult to localise, but he felt sure that by a sort of process of exclusion stray currents might be assumed to account for a good deal of corrosion. He was very pleased to notice in the Form of Enquiry that was being issued by the Corrosion Committee that the stray current question took a rather prominent place, as there were two or three questions on the form referring to that particular point. He thought it would be of interest if some definite instructions could be given for tracing and localising stray currents in a ship in that way. He supposed that, as a rule, the engineers were not provided with any apparatus which would enable them definitely to ascertain whether stray currents did exist or not, and it would be very interesting if some information could be furnished on that point.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), said that no notice had been taken of the gases liberated in water when heated in passing through a condenser; and the possibility of electrical disturbance being set up by the contact of a metal with a gas was just as great if not greater than the possibility of electrical disturbances arising from contact with solid bodies. The point was, he was perfectly convinced, of the utmost importance; and the hint he threw out in some remarks he made to the Institute at a previous meeting concerning the possibility of those solids that were deposited being the centres from which the gases were liberated, was a point that he thought should be taken notice of. It was not the question of any particular gas, it was simply the question of gases being liberated in contact with the metallic surface. Just as in, at any rate, some cases of which particulars had been given the corrosion effected had been greater and more local in the tubes of boilers operating in estuaries and in places likely to be contaminated with sewage, it pointed to the fact that there was a possibility of the gas being responsible for some of the corrosion. The last speaker had pointed out that it was not necessarily confined to any part of the tube. Most writers and observers had, he thought, agreed that the corrosion was most commonly noticeable near the point at which the water entered, and was confined to the forward parts of the tube, exactly what one would expect to take place in connection with the liberation of gas.

Mr. ARNOLD PHILIP, in reply, said that he desired to thank Mr. Bengough, and other speakers who had taken part in the discussion, for their kind appreciation of his communication.

The sub-title of the paper was "The Corrosion of Condenser Tubes by Contact with Electro-Negative Substances," but though he believed that something of the order of 90 per cent. of the cases coming under his notice might be properly attributed to this form of electrolytic corrosion,

combined probably with the exposure of the bottom of the tubes after draining to the simultaneous action of sea water and air, yet he did not at all consider that all cases of corrosion were to be attributed to these actions, the remaining, say 10 per cent. of cases of corrosion were small in number, but nevertheless most important to investigate.

Personally he considered that stray electric currents caused corrosion sometimes, and he believed that he had evidence of this; there were, in fact, many other causes of corrosion, but he did not think that the corrosion set up by all these other causes taken together occurred so frequently as was the case of the particular type with which he had dealt in the title to the paper. It was not possible to make such a descriptive title fit a paper comprehensively, and he had clearly called attention to the alternative possibility of the conditions of draining out a condenser when standing idle setting up corrosion along the bottom of the tubes. With further reference to this latter cause of corrosion, it would be noticed in Case III. on page 49, that out of the five electric generating station condensers, those which were standing idle most often caused the most trouble. If, when out of use, these condensers were allowed to stand full of water which contained electro-negative conducting materials, these would settle out along the bottom of the tubes, and the electro-negative contact theory would explain the fact that tubes were more likely to corrode the less the condenser was used. But, on the other hand, the difficulty of draining horizontal condenser tubes, if the condensers were emptied when not in use, would equally explain the extra corrosion of the less used condensers. The condensers referred to in Case III. were, however, stated to be drained out when not in use.

With reference to the origin of the schedule of inquiries which appeared on page 52 of this paper, he thought Mr. Bengough was mistaken in supposing that this had ever been published before. It had never been published, but it had been read over to and discussed by the Corrosion Committee in March last. There was one further remark he desired to make with regard to the schedule. Mr. Bengough had stated that the schedule printed in the paper was identical with the schedule which the Corrosion Committee had sent out, *i.e.* that the questions asked by the Corrosion Committee were the queries asked for in the schedule which were used at Portsmouth. He did not think that was the case, for the schedule issued by the Corrosion Committee contained very wisely a great many more questions. It omitted, however, questions 6, 7, 8, and 9 in the schedule given in the paper, which were addressed to finding out how the condenser was treated when it was standing idle. These questions were:—"6. Has condenser been continuously in use? 7. If not continually in use, state, if possible, the approximate total periods of use and disuse. 8. When condenser is not in use, has it been the custom to leave the cooling water in the condenser or to drain it off? 9. If water is drained off, are tubes dried by steaming?" He understood from Sir Gerard Muntz that it was proposed to make further additions to the inquiry form later on, and he hoped the Committee would then favourably consider the introduction of those questions

relating to the condition of the condenser when out of use. He begged to thank Admiral Corner for his very kind remarks.

Mr. Vaughan Hughes had inquired whether information had been obtained from the officers dealing with the condensers in which corrosion had been observed. The reply was in the affirmative, the paper being largely a collection of other people's results. He obtained the information from the Admiralty officers, and then registered it. If it appeared in the paper as if he had obtained it by his own research, it was incorrect. The information had been received from various naval officers, and personally he felt very grateful to them for the trouble which so many had taken in supplying it. With regard to the question of the appearance of the corrosion patches, he had stated in the paper that when the corrosions occurred along the bottom of the tubes, he had particularly noticed that the patches were almost always elongated in the direction of the axis of the tube, and this was probably what one would expect.

He had been much interested in Mr. Seaton's remarks with regard to vertical tubes. Theoretically he had proposed the use of vertical tubes, but after all it was a question which must be settled by considerations as to head room and so forth on board ship. Probably the question of getting at the different parts of the condenser, which was a large piece of apparatus, and the limited room on board ship, made it rather difficult to use the vertical form; but the use of this type had been proposed, and he believed had in the past actually been employed in some exceptional cases on board H.M.'s ships. He was particularly interested in Mr. Seaton's statement, that where the condensers had been satisfactory the tubes had been vertical, and that trouble had at once commenced when the same tubes were used in a horizontal position. With regard to the question of robbing the iron to pay the condenser tube, or, as Mr. Seaton put it, robbing Peter to pay Paul, Admiral Corner had already called attention to the very big corrosion of the iron that did occur when iron was used on the condenser on the sea-water side. Generally speaking, one of the indices to an unsatisfactory connection between the tubes and the protector was that the protective zinc or iron did not show signs of corrosion. If a condenser was examined in which corrosion had been going on, it was very often the case that the protector bars did not show a satisfactory corrosion, in fact, that protection did not exist.

COMMUNICATION.

Mr. ARNOLD PHILIP wrote in further reply to the discussion that he thought that Mr. Anderson believed with him that the method of using zinc, iron, steel, or aluminium as protector metals was the most hopeful line along which to attempt to prevent corrosion in condenser tubes. As far as he was aware, practically all causes of corrosion could be nullified by the

electromotive force set up by protective masses of electro-positive metal in electrical contact with the tubes. The paper which he had written dealt only incidentally with the question of the best methods of preventing corrosion, but treated in particular of one, or at most two, classes of corrosion due (a) to the contact of electro-negative conductors, and (b) to the action of water left along the bottoms of tubes after draining, an action to which attention had frequently been called in the past. Those causes of corrosion were what had produced 90 per cent. of the cases which he himself had come across in practice. In spite of the first of those causes however, and of many others which had been recognised, corrosion would not take place if a suitable protective device were used of the character now employed in the navy, provided satisfactory contacts could be maintained. It was only on the breakdown of those devices that corrosion appeared. Mr. Anderson's own applications of that method, which had been extremely well thought out in detail, and had been in practical use for a period of over seven years, appeared to the writer to be at the moment the most satisfactory design available. Devices on those lines would probably obviate all localised corrosion in the future, provided their action could be maintained unimpaired. It was in the cases in which some breakdown in the details of those preventive arrangements occurred that trouble appeared. In the navy, although, as he had pointed out, such breakdowns were infrequent, it was desirable that they should be entirely prevented, and Mr. Anderson's devices might possibly secure that object in a practical manner, and at any rate, in the writer's opinion, his methods appeared the best proposed up till now.

Mr. Anderson's gibe at an "Admiralty mixture" tube as met with in commerce was, he feared, justified. Such descriptive names were frequently apocryphal, but were at least a tribute to the generally high character borne by the real article. Owing to the admittedly doubtful nature of the description of those tubes, and to the fact that Mr. Anderson did not appear to have verified the compositions of the tubes he dealt with by means of chemical analysis, it was not possible to draw any further deductions as to the advantageous character or otherwise of Admiralty composition from what Mr. Anderson had related of his experiences of corrosion.

It must not be assumed that the localised action which had been observed in 90 per cent. of the corroded tubes, as described in the paper, was equally evident in the remaining 10 per cent.; that was not the case, and he hoped to deal further with observations he had made upon some of those 10 per cent. at a later date.

Stray currents from electric light and power leads, with perhaps some fourteen other causes, he fully recognised as being capable, under certain conditions, of setting up corrosion, but he had not attempted to deal with those in his paper. In the navy stray currents were normally very carefully provided against by double wiring and high insulation, whilst special provision of sensitive apparatus for the detection of leakage currents was made, and frequent insulation resistance tests were carried

out. Nevertheless, afloat as ashore, accidents would occur from time to time, and he believed that there had been evidence occasionally that electric leakage had temporarily existed and had caused corrosion. In concluding his reply to Mr. Anderson's remarks, he must express the interest and satisfaction he had felt in listening to the views of one who had made such a very thorough study of this question from the practical side. Mr. Anderson might almost be regarded as a specialist condenser tube doctor, whose patients were, however, chiefly drawn from the very large class of the mercantile marine condenser and shore installations.

Mr. Rhead's remarks were, he thought, chiefly directed to calling attention to the action which gases played in assisting corrosion in condenser tubes, and generally he fully endorsed his views. In his (the author's) own communication he had, however, carefully limited his remarks to very special cases of corrosion, and had intentionally excluded the consideration of all others. He trusted that Mr. Rhead would not consider that he underrated the importance of the causes of corrosion to which he had called attention, because on account of want of time, and as being outside the scope of his communication, he did not enter further into a discussion on this matter.

In conclusion, he wished to remark that on having the opportunity of seeing Mr. Bengough's contribution to the discussion in print, he noticed that that gentleman was under the impression that the present was the first occasion that the writer's views on the corrosion of condenser tubes had been published. That, however, was a misapprehension, for, besides his contribution to the discussion on Admiral Corner's paper, he had stated his views on the general subject fairly fully on pp. 98 to 100 and pp. 109 to 112 in vol. v. of the *Journal* (No. 1, 1911). Mr. Bengough had asked as to whether he (the writer) objected to being "pinned down" to all the deductions Mr. Bengough had made from his paper. He would not raise any objections now, but he hoped he would allow him to protest later if the position became too painful.

FURTHER EXPERIMENTS ON
THE CRITICAL POINT AT 470° C. IN
COPPER-ZINC ALLOYS.*BY PROFESSOR H. C. H. CARPENTER, M.A., PH.D.
(THE UNIVERSITY, MANCHESTER).

A YEAR ago a Research was published by Mr. C. A. Edwards and the writer, entitled "A New Critical Point in Copper-Zinc Alloys: Its Interpretation and Influence on their Properties."† This critical point was found to occur at 470° C. in all alloys containing the so-called " β " constituent as a separate structural entity, *i.e.* from about 63 to 40 per cent. of copper. The interpretation advanced by the authors was that "at 470° C., on cooling, β splits up into an intimate mixture of α and γ ; on cooling, the reverse change takes place." This resolution of β into $\alpha + \gamma$ the authors considered they had detected microscopically in an alloy containing pure β , just above 470° C. It appeared, however, to be only visible at very high magnifications. Photographic evidence in support of this view was given in the paper, and also of the homogeneity of β above 470° C.

The experimental data which constituted the evidence for this interpretation were not questioned by anybody either in the lengthy discussion or voluminous correspondence which followed. The interpretation, however, was challenged. It was alleged by Messrs. Rosenhain, Huntington, Desch, Hudson, and Johnson that the photographic evidence for the duplex structure demanded by the theory given in the paper was inconclusive. The grounds for this criticism were perfectly valid. What is required is a careful *visual* examination at a magnification of at least 1000 diameters. It was only after numerous tests of this kind that Mr. Edwards and the writer concluded that below 470° C. the alloy is inhomogeneous.

* Read at Annual General Meeting, London, January 17, 1912.

† *Journal of the Institute of Metals*, No. 1, 1911, vol. v. pp. 127-193.

Another objection was raised by Messrs. Desch, Guertler, and Rosenhain, who drew attention to the non-coalescence of the so-called $\alpha + \gamma$ complex, even after the three weeks' annealing experiment at 350° – 400° C. carried out by the authors, and asserted that if the theory was correct this coalescence should take place to such an extent as to render the α and γ particles visible at much lower magnifications than 1000 diameters. This criticism is very important, and it must be satisfactorily met before the above theory can be regarded as established. Accordingly, as explained in a footnote by the writer (p. 193) at the conclusion of the joint paper, fresh experiments were set in hand by him in order to obtain decisive microscopical evidence of the interpretation of the critical point. Before describing these, however, it is worth while to consider in as general terms as possible the way in which a one-phase system may be resolved at a eutectoid point into two phases, because such an examination should indicate exactly how much weight ought to be attached to the foregoing objections.

The case has actually been considered by Guertler,* and the accompanying diagram (Fig. 1) has been modified from his Fig. 139. d is the eutectoid point at which, on cooling, phase III. is resolved into the double phase I. + II. There is no need to consider supercooling, because the cooling curves given in the previous paper show that this does not occur to more than a very slight extent. Consider the case of an alloy of the composition d cooling from the solidus line.

The instant it passes below $c d c$, nuclei of I. and II. are formed. If this resolution takes place at all points throughout the mass at the same time, the result will be a perfectly uniform mixture of nuclei of the two types, which may or may not be crystalline, and the newly formed molecules will be in a state of such intimate mixture, that it will be visually impossible to detect any change whatever. On the other hand, if the nuclei of I. and II. are formed haphazard in certain places separated from one another to an appreciable extent, these will exert a decided influence on the mode

* *Metallographie*, pp. 309–313.

of separation of the remaining undecomposed molecules of III. if the temperature is high enough for diffusion to take place. In this event, with the progressive decomposition of III., the resulting molecules of I. and II. will tend to be drawn to the existing nuclei of I. and II., and in due time the aggregations will become so considerable that visible crystals will result. Therefore, in Guertler's words,* "Whereas, on passing the eutectoid point on cooling, the resolution of

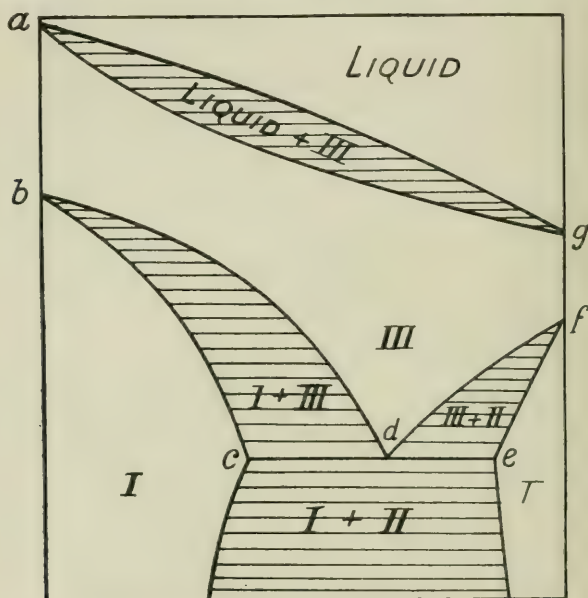


FIG. 1.

III. into I. + II. depends on the velocity of reaction only, and not on diffusion and other secondary influences; yet if the resolved products are to result in a visible form, diffusion phenomena must become active in order that the newly-formed or forming particles may be attracted to those that are already present." Accordingly, if in the particular case of the copper-zinc alloys the β constituent is resolved at 470° C. into a very uniform and intimate mixture of $\alpha + \gamma$ simultaneously throughout the mass, and if diffusion takes place

* *Metallographie*, p. 320.

very slowly at temperatures below this, then the fact that even after a three weeks' annealing at 400°C . crystals of $\alpha + \gamma$ visible at low magnifications do not appear, is not in itself decisive evidence that it is not a two-phase system. Especially will this reasoning hold if the particles of α and γ are amorphous, as they may quite well be in a system where the molecular inversion appears to have taken place uniformly throughout the mass. In fact, the system may come into the category of what Benedicks has aptly called "*Feste Kolloide Systeme in der Metallographie*."* The fact remains, however, that if the inversion of β at 470°C . is a eutectoid change into $\alpha + \gamma$, it is the only known instance of which the writer is aware in which it has thus far been impossible to demonstrate the existence of the inversion products at such a magnification as 200 or 300 diameters. It appeared therefore in the highest degree desirable to initiate fresh experiments with a view to testing the theory more rigorously than it had been done in the joint paper, and to seeing whether the inversion products could not be rendered visible at a magnification of 150 diameters.

The annealing experiments recorded in the joint paper were carried out at temperatures between 350° and 400°C . At such temperatures the molecular mobility in the solid may be very slight and diffusion slow. If the mean of the inversion temperature on heating (470°) and cooling (457°) be taken, viz. 463° as the most probable figure, it will be seen that this is about 60°C . above the highest temperature used. As the rate of diffusion tends to rise with rise of temperature, it appeared desirable in the first instance to anneal β at a temperature as little removed as possible below 460°C . Even at this temperature molecular mobility may only be slight. Curry† found that in the case of the copper-aluminium $\beta \longrightarrow \alpha + \gamma$ inversion which occurs at about 566°C ., thirty days' annealing at 500° were necessary before the constituents were completely aggregated. Time therefore is an important factor to consider in devising experiments on these lines. After some preliminary experiments,

* *Zeitschrift für Chemie und Industrie der Kolloide*, 1910, pp. 290-299.

† *Journal of Physical Chemistry*, 1907, pp. 432-433.

the thermostat finally chosen was a sulphur vapour bath. This gives a constant temperature of 444.7° C., with a variation of about 0.09° C. per millimetre mercury change in pressure. It will be seen, therefore, that this allowed for temperature variations caused by barometric fluctuations, and still left a margin of at least 10° C. below the inversion temperature. Messrs. Waidner and Burgess* say, "In spite of the complexity of sulphur in its chemical behaviour, such as possessing several valencies and isomeric forms in the solid and liquid states, the fixity of temperature of its vapour during boiling appears to be all that could be desired." Preliminary experiments showed that the liquid can be boiled for weeks together without any bumping, and the author has found it a most convenient thermostat for the experiments about to be described.

A specimen of so-called pure β was cast as nearly as possible in the middle of the β area in the Shepherd diagram. This area extends, according to him, from 53.5 to 51.0 per cent. of copper, giving 52.25 as the mean. The analysis showed

	Per Cent.
Copper	52.12
Zinc	47.85

A microscopic examination was made, and the alloy, as expected, was found to consist of the typical large areas of apparent β . Owing to the volatility of zinc in β alloys at 445° C., it would in any case have been necessary, whatever the thermostat, to heat it in a closed vessel to prevent changes of composition occurring. Still more is this, of course, necessary in a sulphur vapour bath. Accordingly, two specimens of the alloy were sealed up in a small glass cylinder under somewhat diminished pressure, and this was suspended in the vapour of sulphur in the apparatus shown in the accompanying Fig. 2. This test was continued for six weeks. The sulphur only burns away slowly, and the addition of a small quantity from time to time is the chief attention required. There is also a decided sublimation and condensation on the cooler parts of the apparatus, which can easily be remedied

* *Bureau of Standards*, Reprint No. 149.

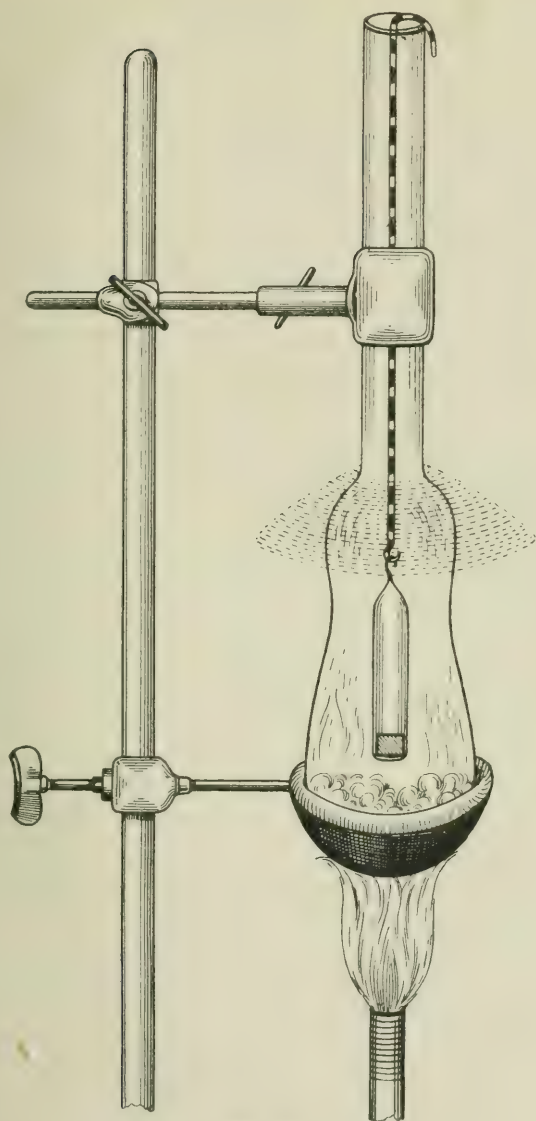


FIG. 2.

by poking the condensed product into the liquid. A microscopic examination at 150 diameters of the alloys after this test, showed that in most parts the apparent β crystals had grown appreciably. There were places, however, where signs of breaking up of the original crystals were evident, but with this was not associated anything that could be called the separation of crystals of either α or γ in a coarse crystalline form, visible at low magnifications. Broadly speaking, no resolution of the original apparent β areas had occurred.

The above test of course is as severe as could have been devised, since, if the critical point is a eutectoid inversion, this particular alloy consists entirely of the eutectoid mixture, and in the absence of comparatively coarse crystals either of α or γ , there may be, in spite of a certain molecular mobility and consequent diffusion, no particular tendency to coarse aggregation in such a mixture. Accordingly, the following test was planned:—Two alloys should be prepared. The one should be of such a composition that it is just outside the β area on the α side, *i.e.* it must contain a little more than 53.5 per cent. of copper, and it will consist of a certain number of α crystallites, distributed through a mass which is in other respects apparent β . If this apparent β is really $\alpha + \gamma$, then on annealing this alloy sufficiently long, provided diffusion is operative, the α crystallites should draw α out of the $\alpha + \gamma$ eutectoid, forming coarse α crystals visible at low magnifications, and leave a residuum of γ . The final result should be coarse $\alpha +$ coarse γ , with a slight preponderance of α over the eutectoid composition. The other alloy should be just outside the β area on the γ side, *i.e.* it should contain rather less than 51.0 per cent. of copper. This will consist of γ crystallites in a matrix of apparent β . If the latter is $\alpha + \gamma$, the γ crystallites will, on annealing, constitute centres for the deposition of γ from the eutectoid, and the final result will be coarse γ crystals with a residuum of coarse α crystals, in which there is a slight preponderance of γ over the eutectoid composition. *The net result, however, should be the same in both cases, viz. coarse $\alpha +$ coarse γ , with this difference only, that in the one α , and in the other γ , slightly preponderates.*

The actual compositions of the alloys came out as follows :—

No. 1.	Copper,	54.20	per cent. ;	Zinc,	45.77	per cent.
No. 2.	„	50.35	„ ;	„	49.61	„

These fulfil the required conditions. The former is 0.7 per cent. to the left of the β boundary, and contains this slight excess of α ; the latter is 0.65 per cent. to the right, and contains this excess of γ . In all the experiments to be described these alloys were heated in small sealed glass cylinders in order to avoid any changes in composition.

EXPERIMENTS WITH ALLOY 1 CONTAINING A SMALL QUANTITY OF FREE α .

The etching reagents found most suitable in all the succeeding experiments are either a moderately concentrated solution of ferric chloride in aqueous hydrochloric acid, or a 25 per cent. solution of ammonia (0.88 specific gravity) in water, to which a few drops of hydrogen peroxide are added immediately before use. The magnification of the photomicrographs is, with one exception, 150 diameters. The structure of this alloy as cast and slowly cooled is shown in Plate IV. No. 1. At this magnification it appears a typical β alloy with large darkly etching and apparently homogeneous crystals. Round the upper part of the large almost central crystal will be observed a thin white border, in one part continuous and smooth, in others discontinuous and jagged. This is free α . In the first instance this alloy was heated for three days in a small electrically-heated annealing muffle, fitted with an adjustable resistance, which enabled the temperature to be kept between 420° and 430° C. The microscopic examination of this specimen gave some most interesting information. Certain β crystals appeared entirely unaltered. A very few, not more than about twelve in the entire field, $\frac{5}{8}$ inch by $\frac{5}{8}$ inch, were found to have undergone the typical eutectoid inversion into alternate light and dark somewhat curved lamellæ. One of these is shown in Plate IV. No. 2, surrounded by darkly etching crystals in which a number of white specks (of α) are manifest. This photograph

by itself is sufficient evidence that the so-called homogeneous β is in reality a two-phase system. Part of this particular crystal is shown in Plate V. No. 3 at a magnification of 400 diameters. Its similarity to the well-known iron carbon eutectoid "pearlite" is very striking. Evidently, then, in this specimen there were a number of crystals of exactly the eutectoid composition. It is well known, however, that the lamellar type of eutectoid structure is not stable on prolonged heating. It tends to pass into a granular or even globular variety. The succeeding photograph (Plate V. No. 4) is shown because it illustrates this transformation. A careful scrutiny of this photomicrograph shows not only some comparatively coarse lamellar eutectoid about the centre of the field, just disappearing, but also much finer lamellæ, mixed up with the granular type, into which they are passing. By far the greater number of originally apparent β crystals, however, had been resolved into the type of structure shown in Plate VI. No. 5. They showed a granular structure in which a very large number of white specks appeared on a dark ground. Even here, however, it will be observed that the lamellar type of structure has not entirely disappeared. These white specks are the α crystals coming out of the approximately $\alpha + \gamma$ eutectoid, and there is no doubt that this crystallisation is due to the presence of the comparatively small number of free α crystals originally present which are able to exert their crystallising influence at the temperature of the experiment on the remainder of the alloy. The next photomicrograph (Plate VI. No. 6) shows the crystallisation of α from another specimen heated for ten days in sulphur vapour. This also is of great interest, because it shows two types of crystallisation on one large crystal in the centre. In the upper half the α appears as a series of approximately parallel needles of varying thickness, whereas in the lower half it has come out almost entirely in the form of specks. It will not escape observation that the main band of α on the top of the large crystal is jagged, and that the direction of the jagged edges is the same as that of the needles in the interior. It certainly looks as though the latter type of crystallisation has been induced by the particular direction

of the jagged edges. On the other hand, the α band at the bottom of the large crystal is smooth, and it does not appear to have exerted formative influences on the crystallisation of α in its sphere of influence.

Photomicrograph No. 7 shows the coalescence of α into coarse crystals after three weeks' annealing in sulphur vapour. This is accompanied by a rounding of the sharp edges. A further stage is seen in Plate VII. No. 8, after five weeks at 445° C. This shows the coarse crystals coalescing to large irregularly shaped masses. Finally, Plate VIII. No. 9 shows the enormous α crystals (white), on a dark ground of γ , after eight weeks at this temperature. On this specimen the α crystals can be seen perfectly well with the naked eye. Thus the final result is α (light) + γ (dark) in an extremely coarse state of aggregation such as the theory demands.

One more step, however, had to be taken to make the proof complete. It might be objected that in spite of the precautions taken the composition of the alloy had changed during the above experiments, and that the structural changes shown had been caused by this and not by the coalescence of the products of a eutectoid inversion. To meet this possible objection the specimen, whose structure is shown in No. 9, was heated for twenty-four hours at 700° C. in order to destroy the large crystals and bring about the reaction



After this it was allowed to cool in the ordinary way, and photographed. The result is shown in Plate VIII. No. 10. It will be observed that the structure in No. 9 has been replaced by typical apparent β areas, and that a few specks of α are distributed here and there. This proves that the composition of the alloy has not changed, and that the apparently homogeneous β has really been resolved into the two constituents $\alpha + \gamma$.

EXPERIMENTS WITH ALLOY 2 CONTAINING A SMALL QUANTITY OF FREE γ .

The structure of this alloy, as cast and slowly cooled, is shown in Plate IX. No. 11. When lightly etched it is seen

to consist of large areas of apparent β , while along their original boundaries and, to some extent, in their interiors are dotted crystallites of free γ , which appears as a greyish light-blue constituent (appearing light on the dark β background). No. 12 is typical of the structure obtained after ten days in sulphur vapour. γ appears as a large number of light bluish-grey spots on a ground of apparent β , whose colour may vary from a golden-yellow to a deep brownish-black. The latter appears dark in the photomicrograph, while three small areas of the former, approximately equidistant from one another, appear light. The development of γ is slower than that of α , and in no case were any crystals observed undergoing the lamellar eutectoid inversion such as is seen on the α side (Nos. 2 and 3).

Plate X. No. 13, representing the structure after three weeks in sulphur vapour, is of particular importance. It represents the junction of three large areas and one small area of apparent β , with a considerable development of γ , which, however, does not etch uniformly. In the top left-hand area γ appears *light* on a medium ground. In the top right-hand area it appears *dark* on a light ground. At the junction of these two areas it will be seen that a given γ crystal appears both light in one part and dark in another, according to its position on the apparent β areas. In the large area at the bottom the γ crystals are some of them light, others dark, and others again mottled. But in spite of these differences of etching, there is never any difficulty in deciding which is γ and which apparent β . The explanation of these differences will be given shortly.

No. 14 shows the structure after five weeks in sulphur vapour. In this and in all subsequent specimens tested, γ etches dark.

Plate XI. No. 15 shows the development of γ after seven weeks. Owing to its brittleness it is apt to break up and fall out to some extent in polishing. In this particular instance the three large crystals placed almost horizontally in the centre of the field are parts of one originally very large crystal. For this reason the proportion of γ in any field is generally less than would be anticipated. The condition after nine

weeks' annealing is shown in Plate XII., Nos. 16 and 17, which represent the same field. The former is polished but unetched. The large central crystal appearing in relief is γ . It appears light bluish-grey in a field of pale gold α . On etching, the colour of α does not change, whereas γ is covered with a deep purple film, which is well seen in No. 17. Other characteristic small γ areas can also be located. The reason for the somewhat varying behaviour of γ towards etching reagents during its crystalline development from apparent β is as follows:—The colour of what may be called massive α is pale gold, that of massive γ pale bluish-grey. In the originally cast specimen of apparent β with a few γ crystals, the former is coloured by etching reagents a deep reddish-brown; the latter is unaltered and so keeps its colour. But as the annealing progresses and γ is withdrawn from the apparent β , leaving a relatively higher proportion of α , there comes a moment when the etching properties are reversed; the enriched α areas no longer etch, whereas the γ areas do, and they are covered with the characteristic purplish film. The special interest of photomicrograph No. 13 is now obvious. It represents the moment when this "change-over" has begun in some parts but not in all. It has taken place in the right-hand but not in the left-hand area, and the bottom area is just in the transition stage. After the change-over is completed, γ always etches dark with respect to α .

The characteristic colours of α and γ appear, though not equally well for photographic purposes, in the specimen of No. 1, viz. photomicrograph 9, containing a slight excess of α . Here the γ is the matrix from which α has crystallised, and owing no doubt to the fact that even after eight weeks' annealing the separation of α is still incomplete, the form of the γ areas is rather indistinct, though the characteristic colour can be seen.

Thus the final result of the annealing experiments on No. 2, containing a slight excess of free γ , is the same as that in No. 1 in the sense that the products are α and γ . In order to complete the proof the specimen, annealed for nine weeks, was heated for twenty-four hours at 700° C. so as to destroy the α and γ crystals, and reform β . After cooling it was photographed,

and the result is shown in No. 18. It will be seen that the typical structure of apparent β has been restored, showing that the composition has not been changed.

It appears to the author that the explanation of the critical point at 470° C. in the β constituent of copper-zinc alloys advanced by Mr. Edwards and himself a year ago, viz. that on cooling it is resolved into an intimate mixture of α and γ , has now been proved in an overwhelmingly conclusive manner. Every requirement of the theory has been satisfied, and it possesses all the certitude of verified prediction. The theory demanded that with sufficiently long annealing under the right conditions, the two alloys—No. 1 consisting of apparent β with a small quantity of α , No. 2 consisting of apparent β with a small quantity of γ —should be resolved into a mixture of coarse α and coarse γ ; further, that though the type of crystallisation would be different in the two cases, because in one case α crystallites and in the other γ crystallites were employed to upset the persistent structural equilibrium of the eutectoid mixture, yet the α and γ should etch in the same way in the annealed alloys, and, finally, that by annealing under the proper conditions it should be possible to destroy the coarse α and γ , and reproduce the original apparent β . Each of these requirements has been satisfied, and it appears to the author that all reasonable grounds for scepticism have now been removed, and that this theory is firmly established.

The proof that below 470° C. the so-called β constituent in copper-zinc alloys really consists of a very intimate mixture of α and γ particles is important, because it explains what the author has always regarded as an anomaly in the etching properties of this substance. It has always appeared surprising why β should be coloured so deeply and so rapidly by etching reagents, and further why, although β etched more easily than α , it also etched more easily than γ . The last-named contained more zinc, and might be expected to etch more readily than β . Both these anomalies are now explained. Apparent β colours deeply and rapidly because it really consists of an intimate mixture of minute particles of α and γ , which dissolve very readily in etching reagents. In this respect it closely resembles the so-called "Troostite"

of the iron-carbon system, which is now known to be a similarly intimate mixture of iron carbide and iron. Thus all the conditions for rapid etching are present, and this explains why apparent β etches more readily than well segregated γ . The latter is no doubt electro-positive to the real β , *i.e.* above 470°C ., but it does not dissolve as readily as the extremely fine particles of γ in the $\alpha + \gamma$ eutectoid mixture. When, however, such as under the conditions that have been described γ is withdrawn from this mixture, resulting in an enrichment of α , then the apparent β no longer etches so readily, and it has been shown that it is the γ that then colours so deeply.

It would perhaps be somewhat unnatural not to indulge in any speculations as to the physical condition of the α and γ particles in the apparent β constituent, in the light of the facts that the foregoing investigation has disclosed. The fact that the pure eutectoid mixture does not show the least sign of coarsening or crystal growth even after six weeks at a temperature not more than 15°C . below the inversion temperature, even though diffusion occurs at this temperature, proves how intimate is the molecular mixture of the α and γ constituents, and it can best be explained by supposing that the resolution takes place at all points throughout the mass at about the same time, resulting in an almost, if not quite, uniform mixture of nuclei of the two types. Strictly speaking, these nuclei do not appear to be ultra-microscopic in a slowly cooled specimen. At any rate, Mr. Edwards and the author concluded in their joint paper that the nuclei were visible at magnifications of 1000 and upwards, and this view has been borne out by the results of the present investigation. The question arises however, are these nuclei crystalline, or even microcrystalline? There is an interesting piece of evidence which bears on this question. A specimen containing apparent β is extremely difficult to polish in such a way as to obtain a surface free from scratches. This is a very curious fact when it is remembered that from the point of view of tenacity apparent β is harder than α , which is by no means difficult to polish. But when, as in the experiments described with alloys 1 and 2, the crystals of α and γ visible at

low magnifications begin to make their appearance, the specimen becomes notably easier to polish, and this keeps pace with the growth of the crystals to such an extent that after eight or nine weeks' annealing leading to extremely coarse crystalline development, the alloys are quite easy to polish. This suggests that in the original apparent β the α and γ nuclei are not crystalline, but amorphous and somewhat softer. And this view fits in well with the way in which the eutectoid mixture appears to have been formed, viz. by an almost simultaneous resolution of the β molecules throughout the mass. This constitutes a favourable condition for the production of the inversion product in an amorphous form, because the forces operative in crystal production which have for their result a particular molecular aggregation arranged in a particular way, will not have time to come into play. In fact the eutectoid appears to come exactly under the head of what Benedicks regards as a "solid colloid system." In view of the uncertainty attaching to the exact meaning of the term "colloid," the author, however, prefers not to apply it, particularly as the nuclei have never appeared to him to be strictly speaking ultra-microscopic. The view, however, that the inverted eutectoid is a fine amorphous complex of α and γ appears to fit all the facts, and to explain the impossibility (as yet) of obtaining crystals of α and γ visible at low magnifications from a specimen containing only the pure eutectoid, and the fact that these can be obtained under the proper conditions if a few crystals either of α or of γ are purposely introduced into the alloy.

Although the proof that the β eutectoid below 470° C. consists of α and γ is complete as it stands, it has been confirmed by other experiments devised by the author, based on different reasoning, which it seems desirable to add for the sake of completeness. Curry * found that in order to complete the structural separation of α and γ from the pure copper-aluminium β eutectoid, thirty days' annealing at 500° C. were necessary. Against this Edwards and Andrew showed † that the introduction of tin accelerated this to such an extent that

* *Loc. cit.*

† *Journal of the Institute of Metals*, No. 2, 1909, vol. ii. p. 42.

the separation was complete in about five hours. Mr. Edwards and the author have recently concluded an investigation of a part of the equilibrium diagram of the ternary system—copper, zinc, aluminium—one aspect of which bears on the problem under discussion. In the accompanying Fig. 3 the corners of the triangle represent the pure metals. The sides represent binary mixtures, on the left-hand copper-zinc, on the right-hand copper-aluminium, at the base aluminium-zinc. The pure copper-aluminium β corresponds to 12.4 per cent. of

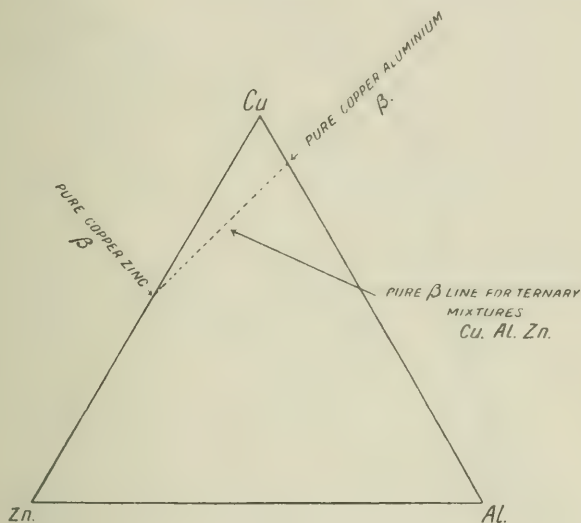


FIG. 3.

aluminium; the pure copper-zinc β , *i.e.* corresponding to the pure eutectoid, occurs at 47.8 per cent. of zinc, as nearly as can be estimated. A straight line joining these two points represents mixtures of copper, zinc, and aluminium at any given point, any one of which corresponds to the pure eutectoid. Attention is directed to two alloys on this line near to the zinc end.

No. 3 had the following composition:—Copper, 61.72; zinc, 34.15; aluminium, 4.01 per cent.

This alloy as prepared had the well-known reddish colour characteristic of copper-zinc β alloys, and, on microscopical

examination, was found to consist of typical apparent β areas of large size.

It was annealed for two days at 445° C., and then examined. The result is seen in Plate XIII. No. 19, and it will be observed

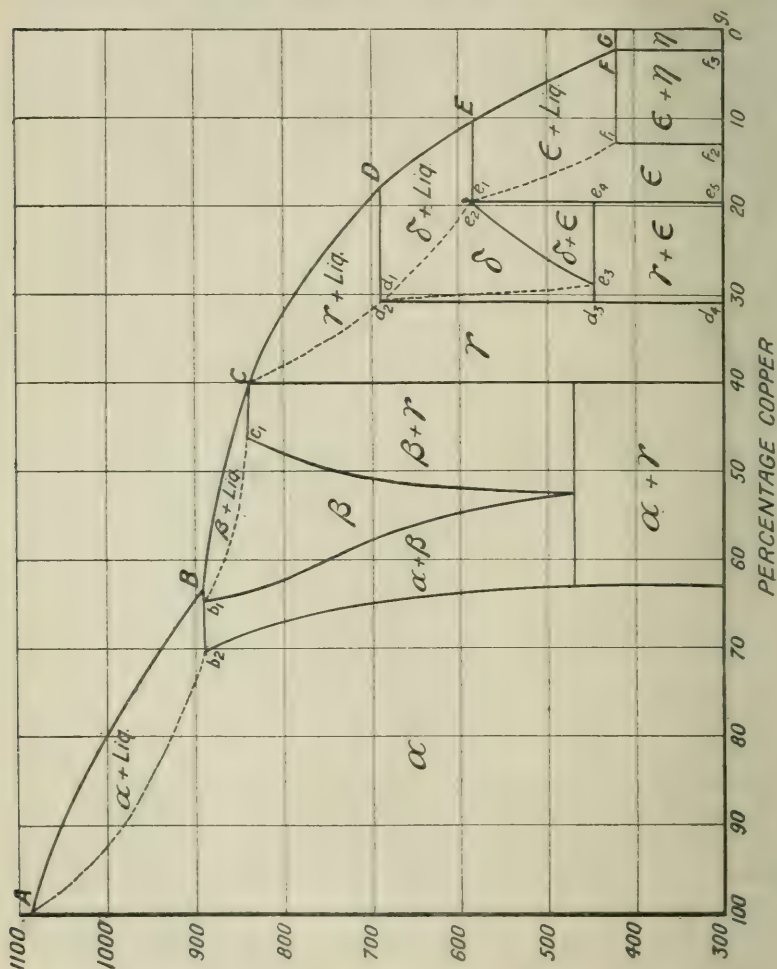


FIG. 4.

that the entire area consists of lamellar α and γ so highly developed that it appears coarse even at 150 diameters. At the same time it was found that the boundaries of the original β areas were unaltered.

No. 4 had the following composition:—Copper, 52.92; zinc, 46.18; aluminium (by difference), 0.90 per cent.

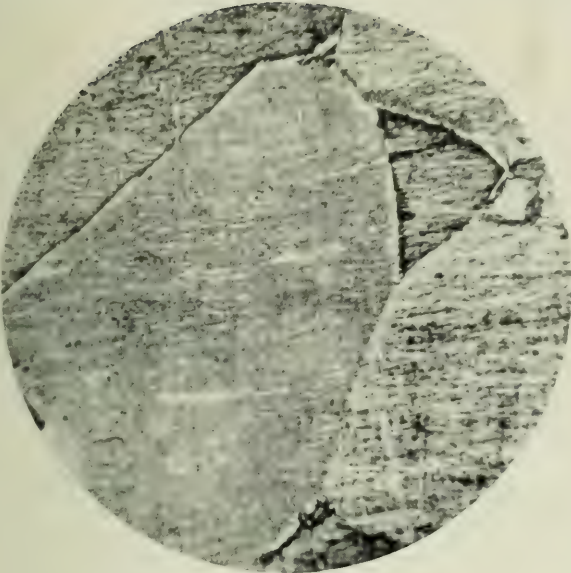
This alloy was not quite on the pure β line, but very slightly on the γ side of it. It had the characteristic reddish colour of β alloys, but it was perfectly brittle. It fractured easily with a golden-red fracture. Under the turning tool no shavings came off, but instead a granular gritty powder. The author interprets this brittleness to indicate that in this alloy the crystalline development of α and γ particles has already taken place to some extent. When polished and etched it showed typical apparent β areas except that they were smaller than usual. Traces of γ were evident here and there. After being annealed for a week at 445°C. , a very pronounced crystallisation of γ took place as shown in Plate XIII. No. 20. On further annealing these crystals developed in an exactly similar manner to those in alloy 2 (*cf.* Nos. 14 to 17 inclusive).

Thus the experiments with these two alloys entirely confirm those recorded with Nos. 1 and 2, and Fig. 4 *must now be regarded as representing the most probable equilibrium diagram of the copper-zinc system from 63 to 40 per cent. of copper.*

SUMMARY.

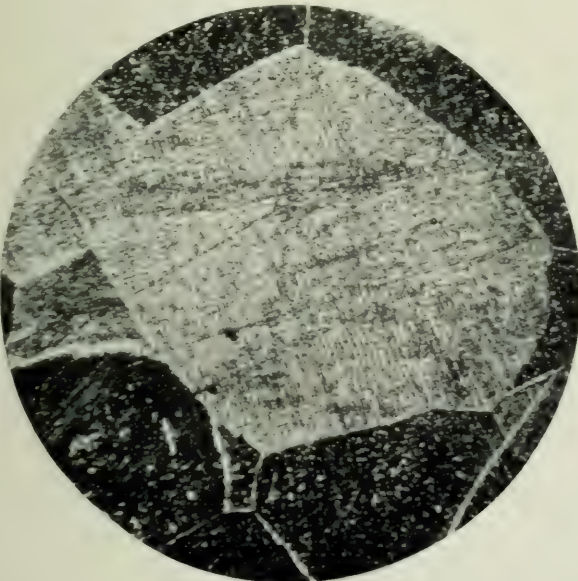
The so-called β constituent in copper-zinc alloys is to be regarded below 470°C. as an extremely minute and uniform complex of α and γ particles. Its structural stability is so remarkable that even after six weeks' annealing at 445°C. , no appreciable coalescence of these particles has been observed in an alloy of exactly the eutectoid composition. When, however, a few crystallites either of α and γ are initially present in an otherwise pure eutectoid alloy, then, on annealing at 445°C. , this stability is comparatively easily destroyed. These crystallites constitute nuclei for the deposition of α and γ , as the case may be, from the mixture, and eventually in both cases the final result is the same, *viz.* coarse α and coarse γ , which can be seen with the naked eye, which have characteristic colours, *viz.* α pale gold, and γ pale bluish-grey, and which have the same etching properties. The peculiarly persistent

structural stability of the pure eutectoid alloy can be explained by supposing that at the inversion temperature on cooling, the resolution $\beta \rightarrow \alpha + \gamma$ takes place throughout the entire alloy almost, if not quite, simultaneously. This constitutes a favourable condition for the production of the inversion products in an amorphous form, because the forces operative in crystal production do not have time to come into play. This view is in harmony with certain peculiarities which the freshly prepared alloy exhibits both in polishing and etching, which disappear when it has passed into a visibly crystalline condition. Further, the structural stability of the eutectoid alloy can be so much diminished by the presence of 4 per cent. of aluminium that after two days' annealing at 445° C. it was found to have undergone the typical lamellar inversion such as is shown by the iron, iron-carbide eutectoid-pearlite. These facts constitute overwhelming evidence that below 470° C. the β constituent in copper-zinc alloys consists of the two-phase system $\alpha + \gamma$.



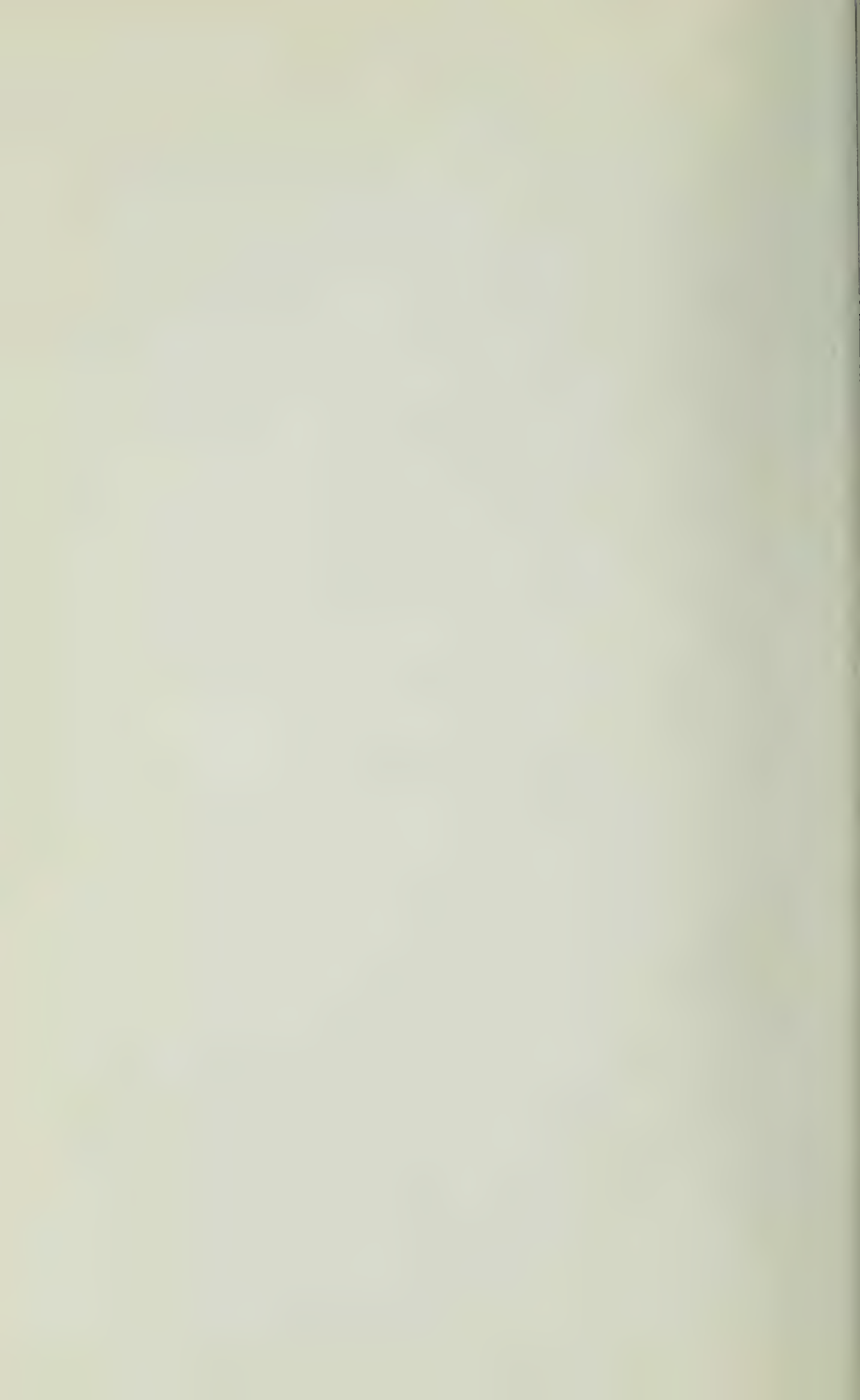
No. 1.

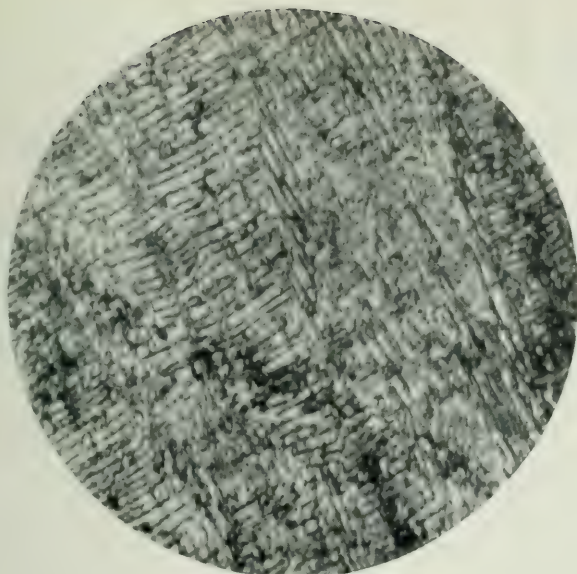
Alloy No. 1 as cast and slowly cooled. Large areas represent apparent β . Thin white border of α visible chiefly in the upper part of the field. Magnified 150 diameters.



No. 2.

Same alloy after three days at 420° to 430° C. showing large area of eutectoid composition undergoing inversion into lamellae of $\alpha + \gamma$. White specks represent α coming out of original apparent β areas. Magnified 150 diameters.





No. 3.

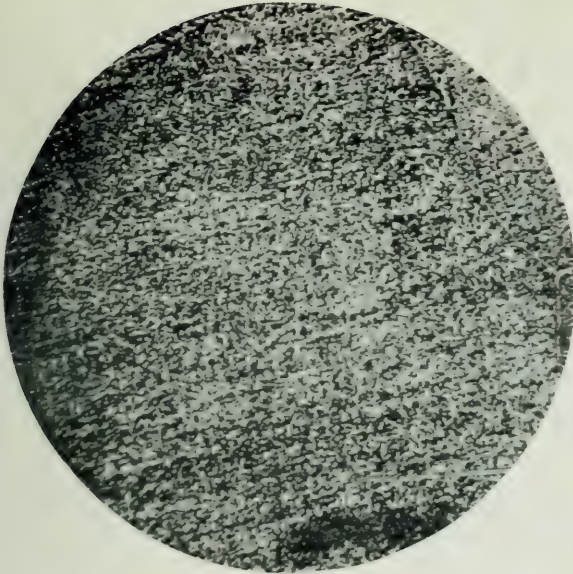
Part of area shown in No. 2 at a higher magnification. The structure is typically pearlitic. Magnified 400 diameters.



No. 4.

Illustrating vanishing pearlitic structure and its replacement by granular decomposition products. Magnified 150 diameters.





No. 5.

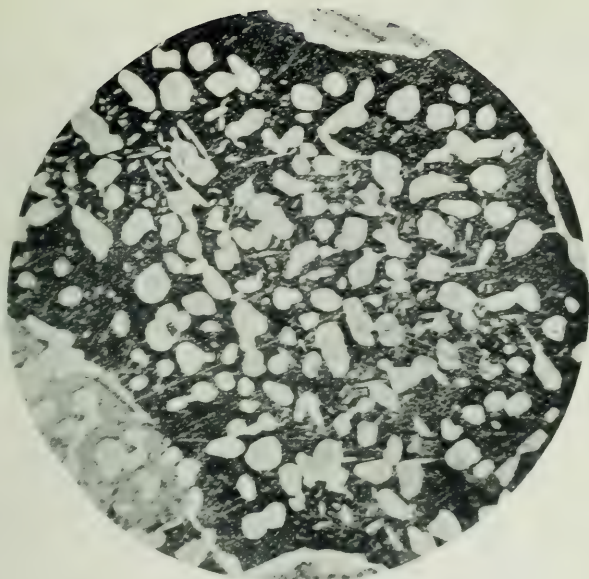
Typical of most of the field after three days at 420° to 430° C.
Traces of vanishing pearlitic structure evident. Magnified
150 diameters.



No. 6.

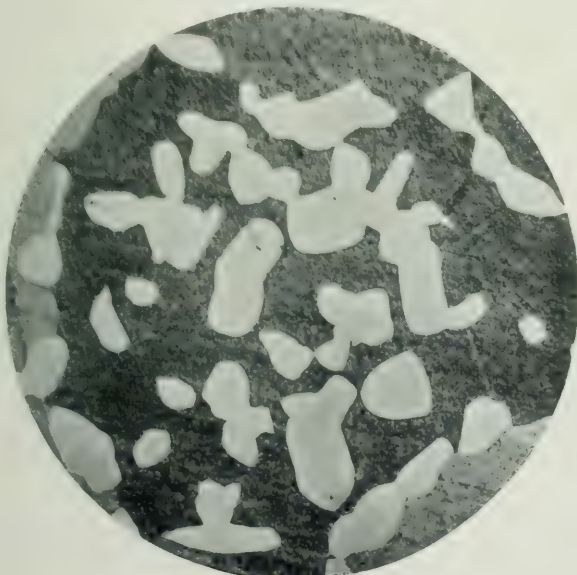
Structure of another specimen of the same alloy after ten days
at 445° C. This shows *a* (white) crystallising out of
apparent β areas. Magnified 150 diameters.





No. 7.

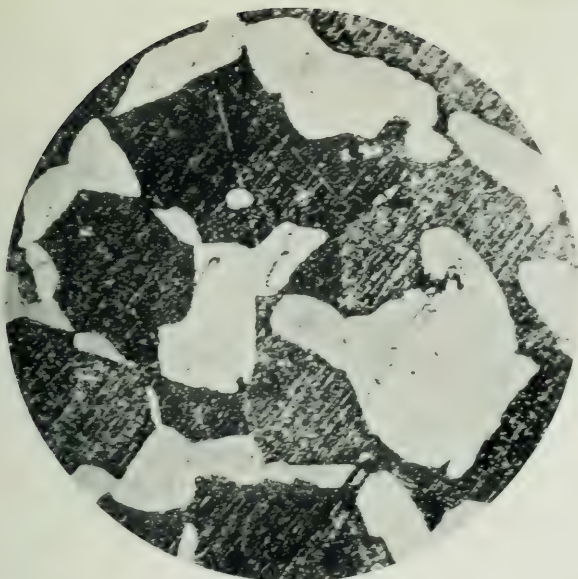
Shows coalescence of α into coarse crystals after three weeks' annealing at 445°C . Magnified 150 diameters.



No. 8.

Further coalescence of α (white) after five weeks at 445°C . Magnified 150 diameters.



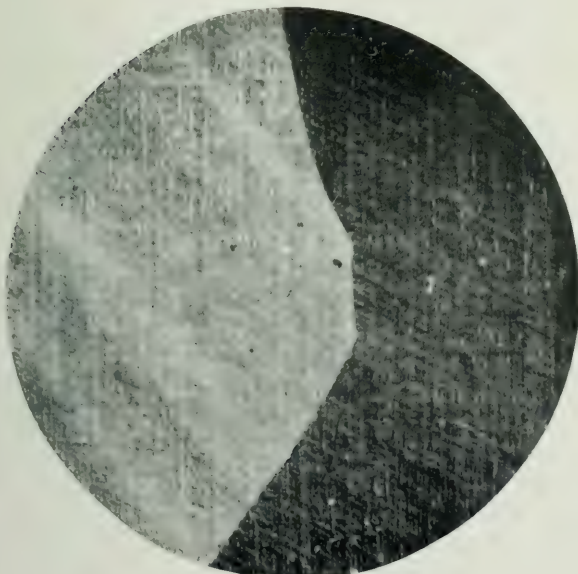


No. 9.

Condition after eight weeks at 445°C . Showing approximate structural completion of the inversion.

α = white ; γ = dark.

Magnified 150 diameters.



No. 10.

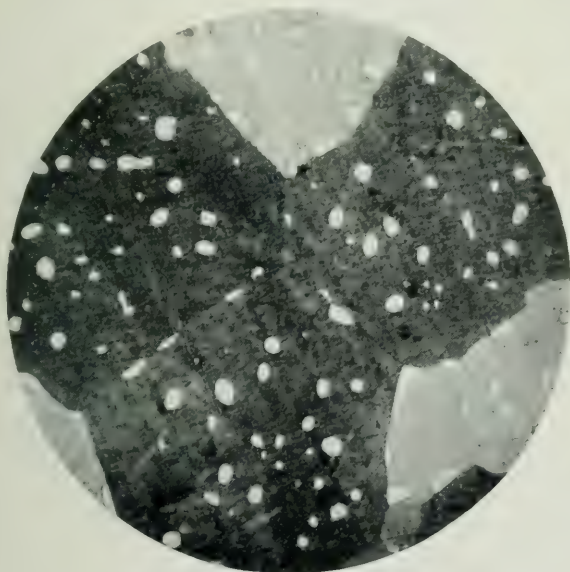
Shows complete destruction of the above structure and its replacement by apparent β areas (with a few white spots of α) after twenty-four hours at 700°C ., followed by slow cooling. Magnified 150 diameters.





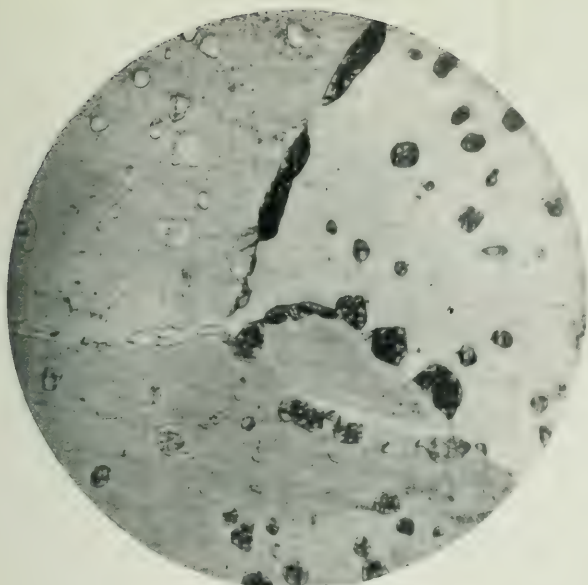
No. 11.

Alloy No. 2 as cast and slowly cooled. Large areas represent apparent β ; light spots, γ . Magnified 150 diameters.



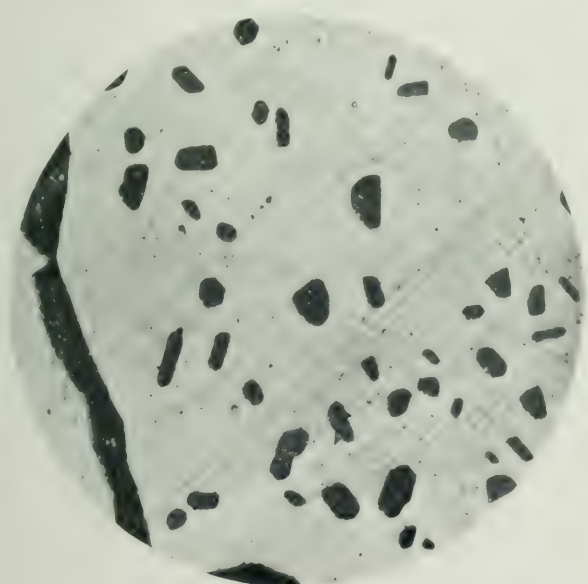
No. 12.

Structure after ten days at 445°C. ; γ (white spots) crystallising out of apparent β . Magnified 150 diameters.



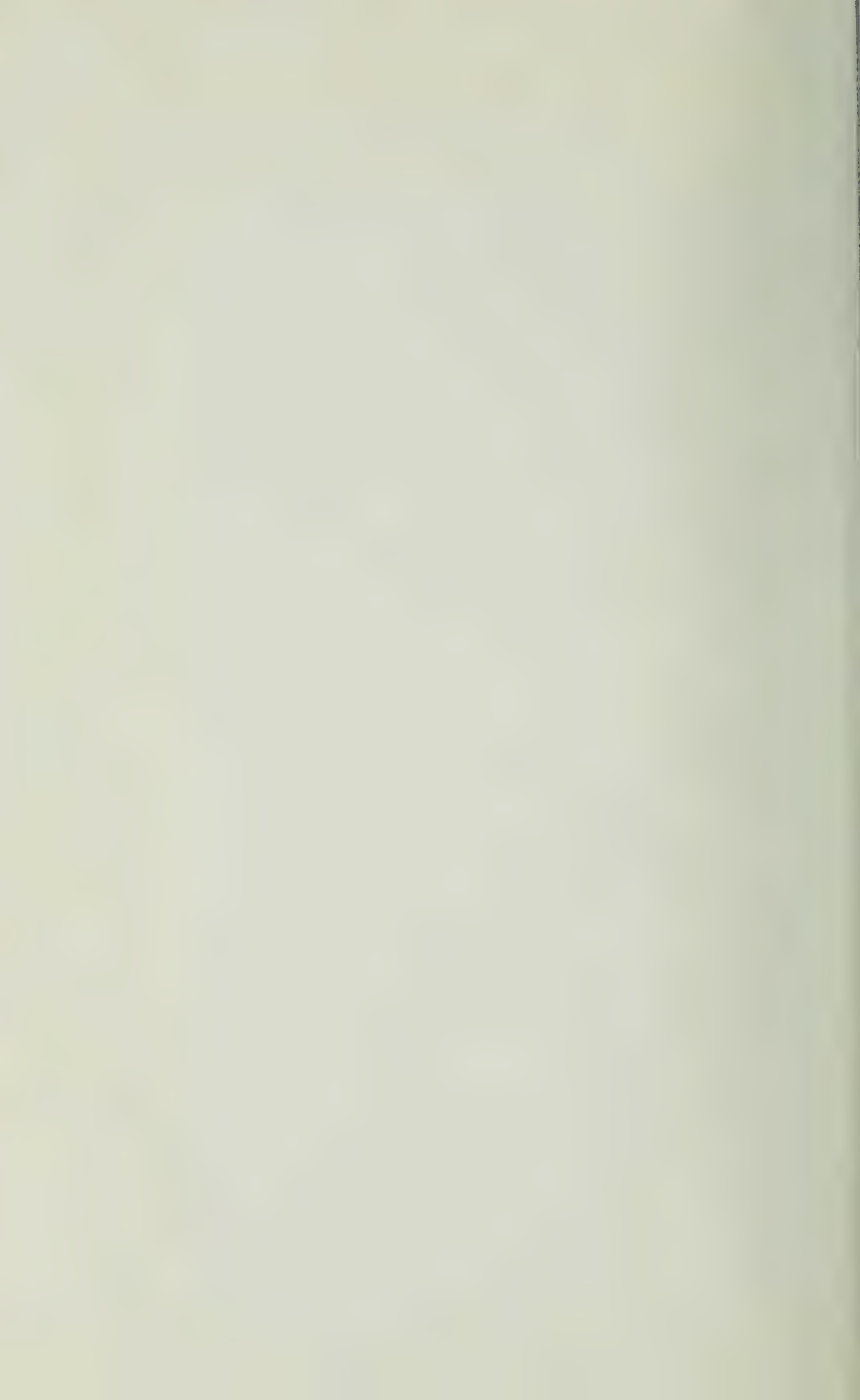
No. 13.

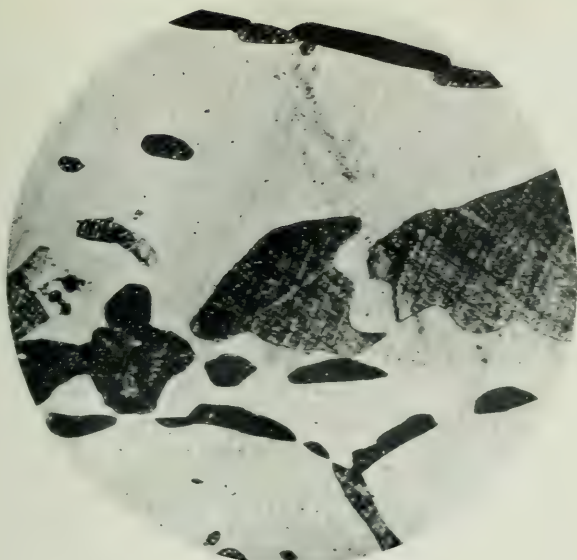
Structure after three weeks in sulphur vapour; γ appears light, mottled, and dark in a matrix of apparent β . Magnified 150 diameters.



No. 14.

Structure after five weeks in sulphur vapour
 γ =dark.
Magnified 150 diameters.





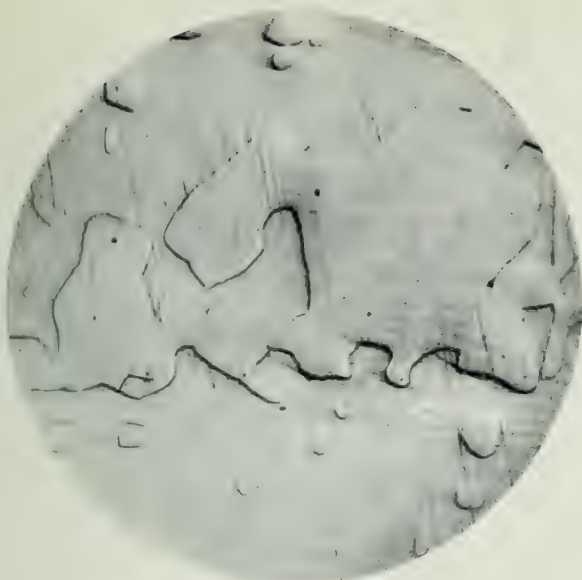
No. 15.

Development of γ (dark) after seven weeks at 445°C .
Magnified 150 diameters.



No. 18.

Shows destruction of $\alpha + \gamma$ areas shown in 16 and 17; replacement by apparent β after twenty-four hours at 700°C .
Magnified 150 diameters.



No. 16.

Structure after nine weeks at 445°C . ; polished, but not etched.

γ =in relief; α =remainder.

See No. 17. Magnified 150 diameters.



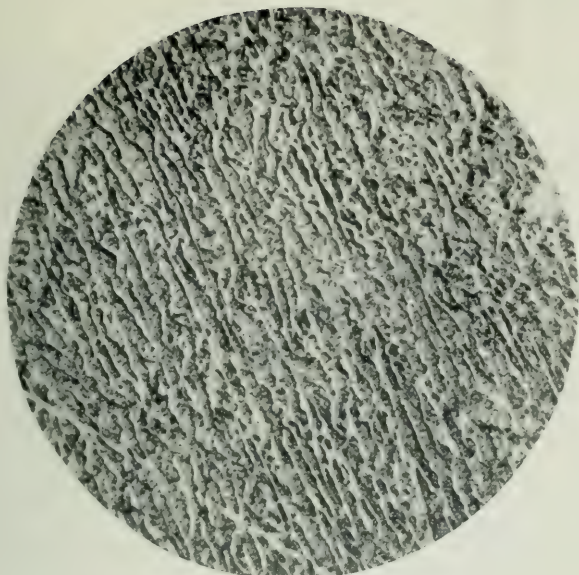
No. 17.

Same area as above etched.

γ =dark; α =light.

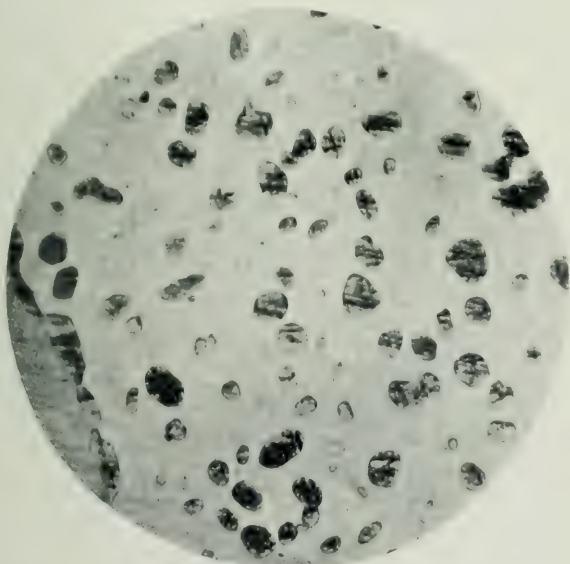
Magnified 150 diameters.





No. 19.

Showing lamellar inversion of apparent β alloy. Cu, 61.72; Zn, 34.15; Al, 4.01; after two days' annealing at 445° C. Magnified 150 diameters.



No. 20.

Showing development of γ after seven days at 445° C. of an alloy of the following composition:—Cu, 52.92; Zn, 46.18; Al, 0.90. The alloy is slightly on the γ side of the pure β line. Magnified 150 diameters.

DISCUSSION.

Mr. O. F. HUDSON, M.Sc. (Birmingham), in opening the discussion, said that as one of those who raised objections to certain portions of the author's previous paper with Mr. Edwards, he wished to say that he did not then deny the probable correctness of the interpretation put forward, but rather that he challenged some of the evidence brought forward in its support. The present paper, however, made a most convincing reply, and the author's interpretation seemed to be fully proved by the very beautiful microphotographs contained in the paper. As the author had stated, a point of great importance arising from the work was the resemblance between "troostite" and the β constituent of the brasses. This β constituent was certainly of rather a remarkable nature, and in this connection he desired to mention one point as to the properties of the β constituent. The author had referred to its peculiarities in etching, or what personally he would prefer to call peculiarities in staining. But in addition to that he had never noticed that the β constituent showed any sign of twinning. He had never seen any twinned crystals amongst the β constituent. That, he thought, supported the theory of the complex nature of the substance. There was one point in connection with the paper on which he was not quite clear, namely, that it was a little difficult to ascertain from the microphotographs which was α and which was β . In the first stage the alloys consisted practically entirely of β , and in the one case α , and in the other case γ , increased in amount as the annealing proceeded. Eventually in either case the microphotographs, it was stated, showed only α and γ . The question, then, was when was the β , or apparent β , replaced by α in the one case and γ in the other. It was a little difficult to ascertain anything on this point from the microphotographs. Personally he had tried a few short annealings of some of the alloys. The first alloy that he took contained an excess of γ , but he had not tried any annealing with one containing a slight excess of α , and that perhaps accounted for the fact that he had not been able to get the very fine pearlitic structure which the author illustrated in the paper. It was only, he understood, by the presence of the excess of α that that pearlite form was obtained. With an excess of γ he had found that the amount of γ increased, but the β constituent showed no signs of breaking up into any eutectoid structure. He desired to ask the author if he could give any idea of the mechanical properties of the body whose microstructure was shown in photograph No. 9 on Plate VIII. He imagined that that body would be exceedingly brittle, consisting as it did mainly of brittle γ material.

Dr. A. G. C. GWYER (National Physical Laboratory) said it gave him very great pleasure to take part in the discussion on the author's very interesting paper, which was a continuation of the paper he presented to the Institute in the previous year. He thought the evidence in favour of the author's interpretation was now, as Professor Carpenter himself

said, almost overwhelming. The members might remember that in the previous year two possible explanations were put before them, namely, what might be called the eutectoid and polymorphic theories respectively.

One reason for rejecting the polymorphic theory had been on account of the supposed constancy of the temperature of the inversion, a point with regard to which he was still not convinced, if he might say so with all diffidence. In going from the copper to the zinc side of the equilibrium diagram, the inversion might not happen to be at a constant temperature. The actual temperature difference observed, if he remembered aright, was 12° . That lent colour to the polymorphic explanation, because in the $\alpha + \beta$ range, if β changed to β' , there was always a constituent, the composition of which corresponded to that marked x changing right through. It was present in different amounts, and it would invert at constant temperature. But in the case of homogeneous β the temperature would not be constant; it would run either up or down. The author had not taken any more cooling curves, and it was a point Professor Carpenter had not further mentioned.

In the photographs given in the previous year's paper, it was rather difficult to see the pearlitic structure. It afforded him much pleasure to congratulate Professor Carpenter on the really excellent photographs in the present paper, especially those in which the pearlitic structure was manifest at 150 diameters. There was absolutely no longer any doubt whatever upon that score. That, of course, was the strongest possible evidence in favour of an inversion of that type, where the one constituent broke up into two. Another point to which he wished to refer was that if the explanation was given that the β broke up into β' , the two points x and y were only 2 per cent. apart. If that was so, he thought it was fairly obvious that the change in crystal formation between something of the composition x and something of the composition y would be so very slight that the greatest difficulty would be experienced in recognising it. There was overwhelming microscopical evidence against that suggestion from that standpoint. One of the difficulties which still remained admittedly a difficulty in the way of the eutectoid theory arose from the fact that an alloy consisting of pure β alone could not be resolved into $\alpha + \gamma$ on passing through the critical temperature. It was well known that in the case of a 0.89 per cent. carbon steel there were formed under analogous conditions masses of pearlite; an excess of either constituent was not required.

Professor CARPENTER confessed that he had been keeping what he was about to say up his sleeve, so that Dr. Gwyer might not go too far. He therefore wished to say that he had now resolved pure β without any excess of α or γ to start with.

Dr. GWYER heartily congratulated the author upon having accomplished such a feat, because in doing so he had overcome one of the chief obstacles that had hitherto stood in the way of the author's own explanation. It was unnecessary for him therefore to go on further with that point.

The author referred in his paper to Dr. W. Guertler's tentative explanation to account for the inhibition of an eutectoid change, and he would refer the members, in case they had not already seen it, to the explanation that gentleman gave in his book. He instanced nickel-tin as a case in point, but to his (Dr. Gwyer's) mind Dr. Guertler's photographs did not support his contention. He thought, on the other hand, that the author's did support his contention.

He had been rather puzzled by the fact that in the $\beta + \gamma$ range no evidence whatever of a pearlitic structure could be obtained, and that seemed to him to point to there being some difference between the $\alpha + \beta$ and $\beta + \gamma$ alloys, although he was not prepared with any explanation to account for it. In the aluminium-zinc series, and in the iron-carbon series, a pearlitic structure was invariably obtained throughout the entire range of alloys in which its presence could be predicted from the diagram. Another point which struck him was the fact that addition of aluminium, which might be expected to help matters very considerably, had not done so. One photograph was given in the paper of an alloy containing aluminium, but it was on the side where excess α was obtained, and where the pearlitic structure was enormously intensified. It was perfectly clear in the case of the alloy without aluminium, but it was very much more developed in the case of the alloy with aluminium. Strangely enough the addition of aluminium to the γ alloys did not alter the type of structure, nor give it any of the pearlitic characteristics. That seemed to him to be very remarkable. Another point made in the author's previous paper was that the change from β into $\alpha + \gamma$ occurred at the same temperature of 460° to 470° as that at which Messrs. Bengough and Hudson had shown that remarkable changes occurred in the mechanical properties of 70/30 brass. Several speakers had urged that if the brittleness at that temperature was due to the presence of $\alpha + \gamma$, and no further change was postulated at a lower temperature, the alloy ought to be brittle at the ordinary temperature. He did not think that was a sound argument for rejecting the eutectoid theory, nor did he think it was necessary to suppose that a change must occur further down, because he thought that whenever a fresh constituent appeared, and an abrupt change in mechanical properties ensued, the big change would occur just when the new constituent appeared, and that then as it cooled down and consolidated it was impossible to say whether it would embrittle it or strengthen it. In conclusion, he desired once again to thank the author for his excellent paper.

Dr. WALTER ROSENHAIN, Member of Council, said that he had the misfortune to be detained so that he had only entered the room a few minutes ago and had missed the earlier part of the discussion; he had, however, been just in time for the dramatic surprise which the author had in store for Dr. Gwyer. In view of that incident he felt a little anxious as to what might happen next, and would therefore proceed with considerable caution. There was no need at all for caution, however, in congratulating the author on his excellent paper; his personal congratulations were all the warmer because he (Dr. Rosenhain) had helped to

bring the paper about—he had been one of the “doubting Thomases” whose criticism had led to Dr. Carpenter's further work. It was a very good sign of the value of the discussions which took place at these meetings to see that they brought out new fact—sometimes with startling rapidity. As far as the paper itself was concerned, there seemed to be little room for discussion, because the whole question had been worked out so fully, but one or two points of difficulty remained. The first of these points concerned the “eutectoid” point; he wished to ask the author what actual evidence he had for drawing the two lines to meet at a point, and what evidence for the precise position of the point? This was a departure from the diagram of Shepherd, and as that diagram was presumably based on definite evidence, stronger evidence was required to justify such a change—he did not think lines should be drawn and meeting-points inserted without perfectly satisfactory evidence, and although the author probably had such evidence, its nature was not brought out in the paper.

In the discussion on the previous paper on this subject he had raised the question of the constance of the temperature of this inversion, and had been answered that although the temperature varied on the cooling curves it was constant on the heating curves. This was a satisfactory answer so far as it went, but the discrepancies on the cooling curves must also have an explanation. Now the present paper raised an additional difficulty, since the microscopical character of the inversion differed so much on the two sides of the eutectoid point. The photographs showed this difference very clearly; on the left-hand side of the pure β -point the structure developed was definitely laminated and pearlitic, while on the right-hand side it was granular, and the granulation was often quite coarse. In all other cases of eutectoids known to him, and in the eutectics themselves, which were very much on all fours with these bodies, such differences never occurred except where there was a totally different reaction on the two sides of the eutectoid or eutectic point. The question thus presented itself whether the reactions on the two sides of the pure β -region were really identical either in character or in temperature, and whether the two lines should be drawn to meet in a point or ought to be continued downwards so as to leave a funnel—possibly a very narrow one—of pure β between them. He desired, in conclusion, again to express his great admiration of the paper.

Mr. G. D. BENGOUGH, M.A. (Liverpool), said that he had very little indeed to add to the discussion on the paper, because nearly all the points had already been dealt with. He desired to congratulate the author on what he thought must be regarded as quite a model of what a scientific paper should be. He had all along been convinced that the author's explanation was the right one, but he admitted that the experimental facts that Professor Carpenter had now put before the members were very much stronger and more complete than they were when he read his previous paper. There were one or two points he desired to refer to very shortly, the first being in connection with a point on page 72. It bore on the question of the mechanical properties, which might be a

point of some interest. Did he understand the author to consider that the change which took place from β to $\alpha + \gamma$ was a very rapid change, *i.e.* that β broke down rapidly into $\alpha + \gamma$, and that it was only the segregation of the $\alpha + \gamma$ into a definite crystalline system that was so very slow? Did he understand aright that it was the reaction that was rapid and the segregation that was slow, or was the reverse the case, the reaction being slow?

Professor CARPENTER said the former was the correct statement, namely, that the reaction was rapid.

Mr. BENGOUGH said he was interested in that point because it bore on the mechanical properties, and if that view was accepted he would have to alter some of the wording in his paper which would come before the members in the afternoon. He was therefore anxious to get the author's view with regard to that matter. He imagined that if the reaction was rapid there ought to be a fairly abrupt change of the mechanical properties at the 475° change point, whereas if the reaction was slow it would take some time for the change in the mechanical properties to develop. With regard to the photographs that the author had published, he (Mr. Bengough) had had a considerable experience with β alloys, and he thought the skill with which Professor Carpenter had managed to produce such beautiful photographs was very much to be admired. He had always found that alloys containing pure β were very difficult indeed to get anything like free from scratches, and to prepare in any way similar to that in which the author's had been prepared. He had obtained structures very much resembling the pearlitic structure shown in No. 3 on Plate V., so that he was in a position to be able to confirm the author's work so far as that went. He had never, however, obtained anything like any of the other structures which the author now brought before the members in the remainder of his plates. He had obtained a structure like No. 3 in a Muntz metal which was rather higher in zinc than usual, but he had never carried out the annealing sufficiently long to be able to confirm any of the other photographs which, however, he thought were very conclusive without any confirmation whatever. He desired, in conclusion, to thank the author very much for his most interesting paper.

Mr. F. JOHNSON, M.Sc. (Swansea), said that he felt called upon to join in the discussion on the paper through being arraigned among the sceptics by Professor Carpenter. He wished to say, however, that the objections he raised in the previous discussion were, like those of Mr. Hudson, confined practically to experimental details. He had very little to say, because practically all that was necessary to be said from a theoretical point of view had already been said. He wished simply to echo the remarks that Dr. Gwyer and Dr. Rosenhain had made with regard to the absence of the pearlitic structure from β on the γ side of the diagram drawn by Dr. Gwyer. There were one or two details upon which he wished to ask the author some questions, the first referring to the method adopted

for determining the zinc in the pure copper-zinc alloys. The author seemed to have obtained extremely good results, only 0.03 per cent. short of what theory demands. Another point had reference to the length of time of etching the specimen, which was rather an important one for men who took up that line of work. The next point to which he wished to refer was the inversion of the β phase in Muntz metal. Would the natural structural stability of β persist in a Muntz metal under prolonged heating for quite a long period? He asked that question, because in some experiments carried out by Webb on locomotive firebox stays he employed Muntz metal stays, which were screwed in to copper firebox plates. Some diffusion would possibly take place at the temperature of the experiments, and possibly that diffusion of zinc into the copper of the firebox plate (which he assumed would take place) might hasten or in some way affect the state of aggregation of $\alpha + \gamma$, and possibly afford one reason for the mechanical instability of the firebox stays.

Professor CARPENTER asked what was the composition of the metal to which Mr. Johnson was referring.

Mr. JOHNSON replied that it was Muntz metal. Speaking from a practical man's point of view, the point of view of a man in works who wished to keep himself up to date, in using the equilibrium diagram, it seemed to him rather confusing to any one who looked at the microstructure of Muntz metal when he found two apparently homogeneous constituents, and he was then told that one of them was α and the other $\alpha + \gamma$. He would see no evidence of that at all, and he had no means of obtaining that evidence—in all probability—for himself. He thought it would be as well to make clear in some way or other that the inversion of β into $\alpha + \gamma$ was not evident under ordinary circumstances. He rather thought, judging from the author's discovery, that finality had not yet been reached in the construction of the equilibrium diagram of the copper-zinc alloys. He had recently come across a point connected with the behaviour of a Muntz metal at high temperature. Naturally one would expect to get, according to the diagram, pure β on quenching such an alloy at about 850° C., but that did not by any means happen. He would like to ask the author whether he had done any experiments in that direction, and as to how long it was necessary to keep a Muntz metal alloy at, say, 850° C. in order to convert it into structureless β ? He wished to add his hearty congratulations to those that had already been given to Professor Carpenter for his admirable paper, and for the great ingenuity he had displayed in confounding his critics.

Mr. E. I. THORNE (Woolwich) said that it would be desirable if Professor Carpenter could go a little further, and demonstrate the presence of γ in a 70/30 brass.

In his earlier paper the author stated that "alloys containing only the α constituent are to be regarded as apparently homogeneous mixtures of very minute crystals of copper and β ," and that "this conception provides an explanation of the brittleness and so-called crystallisation

of alloys containing apparently only α that appear with lapse of time at ordinary temperatures."

Until some convincing proof was forthcoming, the foregoing statement could be accepted only as a convenient theory, to be made use of or rejected as desired.

The writer was of opinion that, in the brasses dealt with by the author, some structural change was to be expected as a result of the critical points; but no critical points had been shown to occur in brasses consisting of α alone, except in Roberts-Austen's 1897 diagram; therefore he was sceptical as to the existence of γ in them.

He would like to have seen the full analyses given of the brasses used in Professor Carpenter's research, and also some mechanical tests, as the process of conversion of β into $\alpha + \gamma$ progressed. How much γ would make a 70/30 brass brittle?

One of the troubles experienced in the manufacture of brass cartridge-cases was the apparently chronic disease of cracking spontaneously. Occasionally cracks would occur within a year of manufacture, but after four or five years the increase in the number of cracked cases assumed alarming proportions. The cases were made of the very best materials, so that any idea of secular brittleness being caused through the presence of impurities was precluded. The stresses in such cases vary greatly from point to point.

Spontaneous cracks had also been found in locomotive boiler tubes three years after manufacture, but such tubes were generally left "half-hard."

Is there any relation between spontaneous cracks and the change of β into $\alpha + \gamma$? That is a point that would be of much value if it could be cleared up, because, if the splits were due to phase changes, then it would appear that they were inevitable in cartridge-cases on account of the inverse change of $\alpha + \gamma \rightarrow \beta$ not being possible at a temperature which would not otherwise detrimentally affect such cases. What is the lowest temperature at which the change $\alpha + \gamma \rightarrow \beta$ could be effected with, say, half-an-hour's annealing, such as could be given in works' practice?

He had always ascribed the spontaneous splitting either to the existence of a hard amorphous phase between the crystals and a tendency for this phase to recrystallise, or a tendency to alteration in the crystals. Spontaneous cracks invariably occurred between the crystals.

There was not any difference in the mechanical properties of metal in a new case as compared with a split one. This is surely against the inversion of $\beta \rightarrow \alpha + \gamma$?

Have age cracks been known to occur in fully annealed α brasses?

The CHAIRMAN said, in view of the large number of papers that still remained to be read and discussed, he was afraid it was now his duty to say that the discussion on the paper must stop, and that any speakers who wished to make further remarks on the subject must send them in in writing to the Secretary. He desired, before calling upon the author to reply, to make a few short remarks of his own. The members might

remember that in *Alice's Adventures in Wonderland*, "The carpenter said nothing but the butter's spread too thick." In case the author might take up that position, he hoped he would excuse his making a few remarks by way of antidote. Professor Carpenter had so far had it all his own way, and he therefore thought it would be for the general good to make a few remarks on the other side. Whilst he admired immensely the amount of work the author had done, and the way he had done it, he would like to make one or two criticisms. He wished to emphasise the criticism Mr. Thorne had also made, namely, that no mechanical tests of any sort or kind had been mentioned in support of the very drastic changes which the author stated had taken place. Personally he was in the habit of looking at things from the practical point of view, and it therefore hit him rather hard not to see any note in the paper bearing on practical tests, which one naturally looked for in matters of that kind. Then he wished to make a remark, which he was afraid would bring about manslaughter, with regard to photographs Nos. 2 and 3 on Plates IV. and V. When he looked at those plates, the first idea that occurred to him was that it was a case of slip bands. If the photographs were looked at carefully, it would be seen that the bands were not all in one direction as they would be in a eutectic, but they were cross-hatched. He had frequently had slip bands appear in the case of alloys of that description, and it required very little indeed to produce such slip bands. Even the pressure of polishing would do it sometimes, let alone the action of cutting and filing. If he had looked first of all at photograph No. 4, he would have been inclined to think that there was some eutectic or eutectoid structure there; but in view of photographs No. 2 and No. 3 he saw the possibility that, in the treatment the author had subjected the metal to, a slip-band structure might be developed, and that, assuming them to be slip bands, they would ultimately give an appearance such as was seen in photograph No. 4. All the members knew that the author was an expert in such matters, but, at the same time, no matter how expert a man was, he was very apt to get led away in dealing with microstructures. They were most deceptive things, and required an enormous amount of looking into before it was possible to be absolutely certain. He thought the author would agree with him on that point. In photograph No. 6 on Plate VI., the author pointed out that there was a different structure in the crystal in the upper and lower half. He thought that was perfectly easily explained. The internal α crystals formed at right angles to the boundary surfaces, and it was entirely a question of the angle at which the crystal was cut whether a longitudinal or a cross-section of the internal α crystals resulted. All sorts of thicknesses were obtained, and to his mind that was exactly what was present in the central crystal shown. If the crystals were cut in one part, the section might be more or less longitudinal, while in other parts sections would be obtained belonging to crystals which came from other faces altogether. There were one or two points he desired to bring out with regard to the final photographs. He had worked out what the amount of α and γ should

be, assuming that complete inversion took place, and according to his calculation there should be 60 per cent. α .

Professor CARPENTER asked what that 60 per cent. represented.

The CHAIRMAN replied that it was for the α end of the β containing a little α .

Professor CARPENTER said that contained about 54 per cent. of copper.

The CHAIRMAN said he did not remember for the moment exactly what the copper was on the α side, but he made it that there should be 60 per cent. of α and 40 per cent. of γ if the β were completely resolved. On looking at the photograph, he made out that there was only about 25 per cent. to 30 per cent. of α there instead of 60 per cent., so that after all the weeks, or it might be said months, that had been spent on the work, Professor Carpenter had only succeeded in producing less than half the amount of α which there would be on complete resolution.

Professor CARPENTER asked which plate the Chairman was judging from.

The CHAIRMAN replied that he was referring to the section in photograph No. 9 on Plate VIII. That was the end of the α series. He had two assistants who were working daily on the determination of the amounts of the two constituents; they checked one another, and were very skilful in determining at a glance the amount of α and β . Turning to the γ end, he calculated it would resolve into 45 per cent. of α and 55 per cent. of γ , whereas the author's photograph showed only about 30 per cent. of γ . There seemed to be a big deficiency there.

Professor CARPENTER inquired as to which photograph the Chairman was referring.

The CHAIRMAN replied that he was referring to Nos. 16 and 17 on Plate XII. The author, he was sure, would agree that that was a very big deficiency even after all that length of time. The remarks he had hitherto made had been against the author, but he was now going to say something in his favour. In the photographs that were shown a great deal more α and a great deal more γ were obtained than would be accounted for by the amount of α and γ which would remain in solution under ordinary circumstances. If an alloy was cast and annealed in the ordinary way, a certain amount of α was obtained at one end and γ at the other, but not more than about 15 per cent. of α or γ would thus be got out. That was considerably less than the author obtained, and that was in his favour. The difference had to be accounted for, and some work he had been doing in the last few weeks on quite a different matter appeared to him likely to throw a great deal

of light on the question. He would not go into the subject at the present time, because the work was not completed, but he hoped at the next meeting of the Institute he might be able to bring it forward. He mentioned it because the difference had to be accounted for; and whether he accounted for it successfully or not, somebody had to account for it by some theory, whether it was the author's or another. Those were the main points to which he wished to refer. He would now call upon Professor Carpenter to reply.

Professor CARPENTER, in reply, said that he would like to make his detailed reply in writing, because so many points had been raised to which he could not do justice in the time at his disposal. He wished, however, to deal with one or two of the bigger issues which had been raised by the various speakers, in particular the question as to the exact location of the eutectoid point. He had hoped by the measurements to which Professor Huntington had referred to determine its exact position, but, as he explained in the paper, that was impossible, because the γ constituent was so brittle, particularly in large masses, that it broke up and fell out during polishing; so that any experiments conducted on those lines would give too small a proportion of γ . He had, therefore, been unable to carry out that particular test. He had had it in mind to fix the exact point, because he thought it was necessary it should be fixed. The only other remark he wished to make was that it was of course a great satisfaction to him that his interpretation had now been almost universally accepted. He did not claim that every anomaly had been cleared up. The so-called β constituent of the copper-zinc alloys was an abnormal substance, and must be regarded as such, and it was not to be expected that everything would come out on orthodox lines. One of the anomalies was the fact that on the γ side of the eutectoid point a lamellar structure had never been observed. Personally he had never observed it, and Mr. Hudson's experience had been the same. This anomaly had to be explained, but, taking all the facts into consideration, it could no longer be disputed that below 470° C. the so-called β was in reality α and γ . In addition to having worked on the resolution of the pure β constituent, he was also working on the influence of other metals (particularly those metals which were present in industrial alloys, such as lead), on the segregation of what he might call coarse crystalline α and γ from the parent β . That was very important from the practical side, and he had already obtained some interesting results which he hoped to present at the September meeting. In conclusion, he thanked the members very heartily for the kind way in which the paper had been received.

COMMUNICATIONS.

Mr. H. I. COE, M.Sc. (Birmingham), wrote desiring to have a little further information as to the nature of apparent β . Figs. 2-9 were quite clear, but in Figs. 12-15 the γ constituent appeared to be segregating, leaving a structureless ground mass called apparent β . Did this ground mass show a very fine duplex structure, or was it the α constituent? He would have expected that the coalescence of the γ areas would have been accompanied by the coalescence of the α areas. In the photographs of the first alloy the respective amounts of α and γ did not appear to change though coalescence took place, but the photographs of the second alloy (Figs. 12-15) indicated an actual increase in the area of the γ constituent.

He would be pleased if Professor Carpenter would explain that point a little more fully.

Dr. C. H. DESCH (Glasgow) wrote that Professor Carpenter was to be congratulated on having established his theory of the transformation of the β constituent by evidence of the most complete kind. The criticisms put forward, by the writer amongst others, had been met by an admirably designed series of further experiments. The behaviour of the β alloys of copper and zinc showed some most remarkable and unusual features. The extraordinary stability of the crystals, unless disturbed by contact with one of the neighbouring phases, was something new. It seemed to indicate, as several other recent observations had done, that even apparently simple systems would prove to be more complex if the experiments were prolonged over a sufficient time to allow of equilibrium being reached. It was important to distinguish between chemical and physical stability. It would appear from the paper that the stable state, in the sense of the phase rule, was reached without much difficulty, but that the α and γ phases remained in a state of division which was either ultramicroscopic, or, as Professor Carpenter seemed to think most likely, just within the limits of microscopic vision. The small particles thus obtained, however, were not physically stable, and if given sufficient time would segregate. This seemed to be characteristic of eutectoids, for pearlite also became more and more coarsely granular when heated below its transformation point, whilst eutectics did not, in general, become coarser under such treatment. The influence of aluminium in promoting the segregation was also interesting, and could be paralleled from other alloys.

The modification of the equilibrium diagram of the copper-zinc alloys now proposed did not account for the behaviour of the α brass examined by Professor Carpenter and Mr. Edwards (this *Journal*, No. 2, 1911, p. 140), and it would seem probable that this was rather a physical change, connected with the facts just observed by Mr. Bengough, than a transformation similar to that of the β solution.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), wrote that to his mind there was now no question as to a critical point at about

470° C., and a resolution of β constituents into α and γ by prolonged heating at that temperature.

As he had previously stated, his research in that matter, undertaken some years ago, demonstrated the existence of some change or critical point at about the temperature given by Professor Carpenter. That work was directed towards elucidating some points in connection with the "soaking annealing" at low temperatures of cartridge metal and other brasses.

The investigation of the author was of considerable practical importance. An explanation was now forthcoming for the curious results of a soaking annealing in pots on "low" brasses. Perhaps in the presence of small quantities of other metals "mysterious" failures in process of the 70/30 brasses would also be accounted for, especially when such brasses were repeatedly annealed in furnaces having "cold" or "dead" ends, *i.e.* those in which the temperature in parts was about 470° C.

He had seen many rings of brass wire fracture while being drawn after annealing in pots over night, and especially over the week end. His father had many times narrated how that he had noticed under his pocket magnifying-glass whitish specks in such wire on examining a fresh fracture. Could he have seen this γ constituent in the 63 to 65 per cent. copper brasses? That defect in pot annealing was generally attributed to the quality of the copper or spelter supplied. Usually the suppliers of the metals were called to account. The modern practical man would at once exclaim, "If this γ constituent is formed every time we anneal in the open furnace or in pots, we should be unable to supply users from our works." In the light of the results of the author's research the answer must be "No," provided it was a certainty that no metals other than copper or zinc were present in the alloys which render the formation of the γ constituent impossible, or nearly so, under the annealing conditions.

It was therefore incumbent upon Professor Carpenter to demonstrate (and doubtless he has this further research in hand) which "element" (solid or gaseous), in small quantities, prevented, and which accelerated, the formation of the brittle constituent when low temperatures of annealing were accidentally or intentionally adopted.

He showed that at a higher temperature, and *in time* (*i.e.* 24 hours at 700° C. for a small piece of his alloy), a redissolution into solid solution was effected of the objectionable constituent.

In the writer's own furnace practice he had, as indicated in the last *Journal*, provided for this, by insisting that brass should always be annealed in a space maintained at the proper temperature for the alloy, and that no part of that space should be below that temperature unless the metal were being heated or cooled quickly or slowly depending upon its composition and previous treatment.

In this connection it was interesting to refer to a process for bright annealing rolled brass by heating it in cast iron pots into which coal-gas was forced, while the pots were being heated in a *cooling* furnace during the night. Such brass he had seen perfectly bright after annealing,

soft, but "rotten," to employ the term users apply to such heat-treated metal.

In further reply to the discussion, and in answer to the communications, Professor CARPENTER wrote it was a source of satisfaction to him that the experiments in the present paper had convinced all the "doubting Thomases," with the possible exception of Professor Huntington. The paper had, therefore, fulfilled its purpose, and only points of detail remained to be dealt with.

(1) Messrs. Hudson and Coe asked when apparent β was replaced on the one hand by α , on the other by γ in the annealing experiments. This question only arose when the structures were examined at low magnifications. Under high-power examination (1000 diameters and upwards) the two-phase nature of apparent β was manifest at the outset and throughout the coalescence of α and γ during annealing. At 150 diameters, however, the freshly prepared alloy appeared homogeneous. Except by its colour, the magnitude of its crystals, and, as Mr. Hudson pointed out, by the absence of twinning, it did not appear different from α . During the annealing experiments the only changes that could be seen at that magnification were, in the case of No. 1 alloy, a progressive growth of the α crystallites leaving an enriched γ residue, and in the case of alloy No. 2 the exact converse. The process of withdrawal of one constituent was gradual, and it was only at its conclusion that the complete separation of α from γ or γ from α could be said to have taken place.

(2) No mechanical tests had been done, for the simple reason that they had nothing whatever to do with the problem. The two-phase nature of the β constituent below 470° C. could only be established by metallographic investigation controlled by phase-rule considerations. Professor Huntington's complaint, therefore, as to the absence of mechanical tests was unjustified. Mr. Hudson's suggestion that the alloy, whose structure was shown in Plate VIII. No. 9, would prove to be "exceedingly brittle," was, however, quite correct. The development of massive α and γ from the specimens during annealing was accompanied by an increasing degree of brittleness.

(3) With regard to Dr. Gwyer's references to the temperature of the inversion, the author would say that had any doubt as to the nature of the β constituent below 470° C. remained, further heating and cooling curves would have been taken. The proof of the dual nature was now so complete however, that it would be superfluous to extend the work in that direction.

(4) Dr. Rosenhain asked what evidence there was for a eutectoid point, and also for its exact position. The entire paper was an answer to the first part of the question, but the matter could be briefly stated as follows:—If the lines b_1 and c_1 did not meet, as shown in Fig. 4, then alloy No. 1 would after an eternal annealing still be what it was at the beginning, viz. apparent β with a trace of α ; instead of which, after eight weeks' annealing, it consisted of massive α and massive γ . Unless

the lines met at a eutectoid point, not a trace of γ could have been formed. Similarly, alloy No. 2 could have formed no α . Both those things had been done however, and, quite apart from the other evidence in the paper, they were decisive. As to the exact location of the point, he had dealt with that in his verbal reply.

(5) In answer to Mr. F. Johnson, the zinc was estimated as zinc pyrophosphate after removal of the copper electrolytically. Regarding etching or staining, the freshly prepared alloys stained very quickly, but as the segregation of massive α and γ developed, the rapidity of staining diminished, and reached a minimum in the most completely annealed alloys. Mr. Johnson asked, "Would the natural structural stability of β persist in a Muntz metal under prolonged heating for quite a long period?" The author's view was that it would not, because Muntz metal contained a large proportion of α , and on prolonged heating that would tend to cause the segregation of α from the apparent β complex, leaving an enriched γ brittle residue.

(6) With respect to Mr. Johnson's remarks about the apparently homogeneous nature of β in Muntz metal, the author would say that although constitutionally it was a minute complex of $\alpha + \gamma$, yet, provided it remained at the ordinary temperature, and especially if it consisted substantially of copper and zinc only, it behaved as one structural constituent, and showed no tendency to segregate progressively into larger particles of α and γ , with a resulting development of brittleness. Within those limits it behaved, from a practical standpoint, as one constituent.

(7) In reply to Mr. Johnson's last question, the author would say that he had not carried out those particular experiments, but some information bearing on the point was given on p. 79. He would anticipate that six hours' heating at 850° C. would be sufficient. That would have to be followed by quenching carried out under strictly defined conditions, such as have been determined by Benedicks, if the structure of β was to be maintained.

(8) Mr. Thorne's remarks dealt almost entirely with 70/30 brass. The present paper was concerned exclusively with the change at 470° C. in structurally free β . It was essential to have the proof established there, before basing upon it any reasoning as to possible changes of a similar character in materials such as 70/30 brass. So far as that aspect of the matter was concerned it remained, therefore, in the same position as Mr. Edwards and the author left it in January 1911, *i.e.* to use Mr. Thorne's words, it was "only a convenient theory." With regard to the analyses of alloys Nos. 1 and 2, the author would refer Mr. Thorne to the figures on p. 77, which showed that 99.97 and 99.96 per cent. consisted of copper and zinc. The remainder probably represented traces of oxygen. The spontaneous cracking of brass cartridge cases, mentioned by Mr. Thorne, was of great importance. He himself stated what appeared to be the most probable explanation of this, *viz.* that it was caused by the recrystallisation of the amorphous phase between the crystals which was produced in cartridge manufacture. The instability of such amorphous phases has been shown in the clearest manner by Dr. G. T. Beilby.

(9) Professor Huntington appeared to have considered that it was his genial mission to act as "Devil's advocate" in regard to the present research. His reference to mechanical tests had already been dealt with. Then came a criticism which he foresaw might "bring about manslaughter," viz. that the lamellar structure depicted in photomicrographs 2 and 3 was due to slip bands. That was indeed a hardy suggestion, one degree better than the criticism Professor Huntington made a year before, when he said the structure was due to "polishing scratches." * If the criticism was really pressed, then the reply was: (1) Why did that structure appear only in those particular photographs when the specimens were all polished in a similar way? (2) Why was it found in all stages of development between the complete lamellar and the complete granular type of structure? (3) Why did it fit so perfectly into the behaviour that might be expected if the eutectoid theory was correct?

(10) As regards the relative proportions of α and γ to be expected in the fully annealed specimens, the author did not claim even after eight or nine weeks' annealing that complete separation of α and γ had occurred. The tests were merely carried to a point at which very gross structures were obtained. But in any case it was impossible to fix the exact position of the eutectoid by measurements of that kind, owing to the fact that γ was very brittle and dropped out on polishing. In the diagram the eutectoid point had been provisionally placed in the middle of the Shepherd β area of about 52 per cent. of copper.

(11) The practical details supplied by Mr. Vaughan Hughes were of much interest. The investigation for which he asked as to the retarding or accelerating effects that other elements might have on the 470° C. inversion was one that the author had nearly completed, and which he hoped to present at the September meeting of the Institute.

(12) Finally, there was characteristic of the β constituent which constituted a stumbling-block to some in the way of the complete acceptance of the eutectoid theory, and to which Messrs. Gwyer and Rosenhain had given expression, viz. that the lamellar decomposition of β had never been observed on the γ side of the eutectoid point, but only on the α , whereas, if the theory were correct, the lamellar resolution should be observed on each side. In support of that criticism the case of pearlite had been quoted, which on each side of the eutectoid point was lamellar. It was important to examine that analogy and the argument based upon it.

In the first place, there was no theoretical reason why a one-phase in passing into a two-phase system should produce a lamellar type of structure rather than any other. It did so in some cases, but not in all. The decomposition of copper-aluminium β into $\alpha + \gamma$ at 532° C. was especially interesting, because both lamellar and granular decomposition products had sometimes been observed by the author on one and the same specimen. Even pearlite was apt to show variations of that kind in any given steel.

In the second place, eutectoid austenite, if cooled at ordinary rates

* *Journal of the Institute of Metals*, No. 1, 1911, p. 168.

through the inversion temperature at about 720° C., formed mainly lamellar pearlite. Supposing, however, that it was cooled rather more quickly, so that the so-called sorbite was obtained, a structure entirely free from lamellar characteristics, and supposing that that was afterwards annealed for some hours at 650° C., what would be the result? As was well known, *granular and not lamellar pearlite at all*, because the latter type of structure was unstable on heating. With prolonged annealing the granular pearlite would coalesce and give finally massive ferrite and massive cementite. That constituted an exact parallel both as regards the conditions under which the apparent β constituent was annealed and the results obtained. *The point that the author desired to make was that under those conditions it was precisely the granular and not the lamellar type of decomposition that was to be expected*; and that fitted in perfectly with what was actually observed, viz. if the annealing of No. 1 alloy was interrupted at a very early stage, a few crystals, "not more than about twelve in the entire field $\frac{5}{8}$ inch by $\frac{5}{8}$ inch," were found in the lamellar condition, others in a transition stage to granular, but by far the greatest number were entirely in the granular condition. To represent the lamellar decomposition as being normal and characteristic on the α side was to misstate the case, if it was pressed, as Dr. Rosenhain had done, to the extent of using it as evidence that it was different from that on the γ side. As a matter of fact, although the author had examined other specimens of No. 1 in the early stages of segregation during annealing, he had never again found so marked a lamellar structure as was shown in Nos. 2 and 3. The normal segregation that was to be expected under the conditions of the experiments, therefore, was *granular*, whether on the α or the γ side. If the normal resolution of the β constituent on passing through 470° C. at ordinary rates of cooling were lamellar, it was the author's opinion not only that the early investigators of that alloy would have easily recognised its duplex nature, but also that the properties of Muntz metal would be so different from, and so inferior to, what they actually are, that it would have been very little used as an industrial alloy.

THE
BEHAVIOUR OF CERTAIN ALLOYS
WHEN HEATED *IN VACUO*.*

BY PROFESSOR THOMAS TURNER (UNIVERSITY OF BIRMINGHAM).

I.—EXPERIMENTS ON BRASS.

IN some experiments conducted in my laboratory last session, on the gases in brass, by Mr. J. Cartland, M.Sc., it was observed that when brass is melted *in vacuo* the zinc is entirely volatilised and the copper remains behind. This separation is quantitative providing that the materials employed are pure, and that the heating is not at too high a temperature or too prolonged. Otherwise the copper itself may begin to volatilise, though at 1200° C. the loss of copper occurs very slowly. The following are examples of the results obtained:—

Sample.		By Analysis.	By Loss in <i>Vacuo</i> .
		Per Cent.	Per Cent.
1	Percentage in Zinc.	36.90	36.80
2	" "	28.63	28.85

The experiments were performed as follows: A weighed quantity of the brass was placed in a porcelain boat, and introduced into a porcelain tube, the ends of which were then suitably closed, and the tube exhausted till the pressure was less than 5 millimetres of mercury. The tube was heated in an electric tube furnace of the well-known platinum resistance type until it was seen, through the glass cover at the end of the tube, that the metal was melted. By the aid of a thermocouple placed within the tube of the furnace, but outside the exhausted tube, care was taken that the temperature did not rise more than a few degrees above the melting point of copper. If the alloy is maintained for about half-an-hour at

* Read at Annual General Meeting, London, January 17, 1912.

this temperature, all volatile metals will have been removed from the copper, which, on cooling, is obtained in beautiful prills of a clear red colour, and usually with plainly developed crystal surface markings. The zinc condenses in the cooler parts of the tube in crystals which have a perfect metallic lustre.

In view of these results the question naturally arose as to what would be the effect of heating *in vacuo* an alloy which contained considerable proportions of other metals in addition to copper and zinc. A sample of impure brass was obviously a suitable material for preliminary investigations.

II.—POISONED BRASS.

Occasionally, during the past twenty-five years, when visiting brass foundries in the Birmingham district, I have heard the workmen speak of "poisoned" brass. It is described as being a variety of brass which is no good for casting purposes if used alone, and the evil influences of which are manifest in any alloy of which the poisoned material may form a part. The language employed might at first sight suggest some occult or living power in the brass, and recalls the ideas of an Indian writer who, a few years ago, suggested that metals might be living or dead, ill or well, like animals or plants. No such thought is present in the mind of the workman, however, for he uses the word "poisoned" rather to express a property of the material than to suggest any hidden or deeper meaning. The language of the uneducated metal worker is often that of the science of an earlier age. Thus when a puddler calls the blue flame of carbon monoxide "sulphur," he does not suppose that what he would call "brimstone" is really present, but that some volatile and combustible principle is being evolved or produced. In this way he exactly imitates the philosophers who preceded Priestley and Lavoisier, and who constantly employed the term "sulphur" in a similar manner.

A few years ago a sample of "poisoned" brass was received from Mr. R. H. Best, who regarded it as somewhat of a curiosity, and it was placed in the Metallurgical Museum. It was part of an ingot, nearly semicircular in shape; it was rather

light yellow in colour, had the sharp fracture of a brittle material, and was full of blowholes, some of which were not much less than a quarter of an inch in diameter. Inquiries as to the source of origin of this sample showed that it was made by melting up the general scrap of a foundry. The makers apparently did not consider it sufficiently good for their own purposes, so sold it at a cheap rate. The blowholes were stated to be due to the use of a damp mould, and this may probably be correct, at least in part.

An analysis of the alloy, conducted in my laboratory by Mr. P. T. Brühl, M.Sc., gave the following results:—

	Per Cent.
Copper	72·53
Zinc	11·65
Lead	7·11
Tin	5·52
Iron	2·00
Aluminium	0·75
Arsenic	0·09
Manganese	0·06
Phosphorus	Nil
	<hr/> 99·71 <hr/>

An examination of these figures will fully explain the inferior results which would be obtained on using such an alloy, and would justify the use of the word “poisoned” in the sense in which it is employed by the workmen.

A weighed quantity of this alloy was placed in a porcelain boat and heated *in vacuo* in a porcelain tube to a temperature of about 1200° as before described.

The residue left in the boat from the poisoned brass was weighed and analysed by Mr. C. R. Groves, B.Sc., and the results obtained are as follows:—

Residue in the Boat (by Analysis).

	Per Cent. (on Original Material).
Copper	72·36
Tin	5·01
Iron	1·96
Lead	Nil
Zinc	Nil
Arsenic	Nil

Loss by Volatilisation.

	Per Cent.
Zinc	11·65
Lead	7·11
Tin	0·51
Arsenic	0·09

These results account for about 98·69 per cent. of the whole. The aluminium and manganese were not estimated, on account of the small quantity of the material which was available.

It will thus be seen that when zinc and lead are present together in the alloy in certain proportions, the whole of the zinc and lead may be removed by heating to the melting point of copper *in vacuo*, and the two metals are recovered in the metallic state. The loss of arsenic is also significant.*

III.—CRUCIBLE EXPERIMENTS.

An experiment was now conducted on a somewhat larger scale, in order to test the rate of volatilisation *in vacuo*. For this purpose 180 grammes of 70/30 brass, of good quality, were melted in a clay crucible in a coke fire. About 30 grammes were poured into a small mould to obtain a check sample. The residue, weighing about 150 grammes, was quickly placed in a covered glass desiccator, and a vacuum at once obtained by means of a Fleuss pump. To prevent fracture of the glass, the inside of the desiccator was properly lagged by means of two layers of asbestos cloth, and an intermediate layer of crushed firebrick. The crucible was also covered with a firebrick to prevent radiation. By surrounding the crucible in this way, a red-hot crucible, containing over a quarter of a pound of molten brass, can be kept in a glass vessel for a considerable period without the containing vessel becoming appreciably warm.

The original metal contained as nearly as possible 30 per cent. of zinc. When remelted, the sample cast in the mould contained 70·80 per cent. of copper. The loss of zinc in remelting in an open crucible was therefore about 0·8 per cent. The molten metal was placed in the desiccator, and, after being allowed to remain *in vacuo* for seven minutes

* See Communication, p. 121.—ED.]

was removed and analysed, and found to contain 73·94 per cent. of copper, showing a loss of 3·14 per cent. of zinc. As the metal was quite solid and only dark-hot at the end of seven minutes, it was probably fluid not more than three minutes, in which case the loss of zinc would be at the rate of 1 per cent. per minute. In other words, if by internal heating or other suitable means a charge were kept fluid during the whole period, complete volatilisation of zinc might be expected to take place in less than an hour. Metallic zinc, weighing 4·9 grammes, was actually scraped off the under side of the firebrick cover. A repetition of the experiments with different weights of metal gave almost identical results.

These experiments show that considerable refining of impure copper could be accomplished by melting the metal *in vacuo*, as zinc, lead, arsenic, some tin, and probably other metals, could be volatilised and recovered. There does not appear to be any good reason why such a process should not be experimentally tried on a fairly considerable scale. In these days of electric melting furnaces, and efficient air-pumping machinery, it should not be difficult to design a form of apparatus which would be suitable for treating impure residues and crude coppers. There might perhaps be introduced a process in two stages, in the first of which crude molten metal would be purified by being maintained for a time in an exhausted vessel, while in the second stage the partially purified copper could be refined in an oxidising atmosphere to remove the remaining iron, tin, and other non-volatile metals.

IV.—THE REFINING OF HARD ZINC *in Vacuo*.

Zinc distils readily *in vacuo*; the temperature required is much lower than in air, and the losses are so much diminished, that it is probable means will be devised in future for considerable applications of vacuum distillation in connection with the zinc industry.

The material known as "hard zinc" is produced in the ordinary process of producing galvanized iron. The bath of molten zinc which is employed, and in which iron is being

constantly dipped, gradually takes up iron until it contains about 5 per cent. of the latter metal. The iron-zinc alloy is then unsuitable for further use in galvanising, and is sold to the metal refiner or zinc works to be redistilled. This alloy appears to be specially suitable for refining under reduced pressure.

A sample of hard zinc analysed in my laboratory by Mr. Groves contained:—

	Per Cent.
Zinc (by difference)	94.48
Iron	4.71
Lead	0.81
	<hr/> 100.0

There was also present a trace of arsenic; but tin, copper, cadmium, antimony, and bismuth, though tested for, were not in sufficient quantity to be detected.

This hard zinc was tested by heating 1 gramme *in vacuo* for varying times at different temperatures. In all cases the pressure in the evacuated porcelain tube was less than 1 millimetre of mercury. The results of the tests are given in the following table. The percentages are calculated on the original sample.

Heating of Hard Zinc in Vacuo. Analyses by Mr. Groves.

Temperature, Degrees Centigrade.	Time, Minutes.	Iron in Residue, per Cent.	Iron Volatilised, per Cent.	Zinc in Residue, per Cent.	Lead in Residue, per Cent.
1000	15	2.08	2.63	Nil	Nil
600	30	2.32	2.39	Nil	Nil
550	30	3.42	1.29	Nil	Nil
500	45	4.70	Nil	0.40	Nil
500	45	4.80	Nil	1.52	0.30

In the second experiment at 500° C., the furnace was heated more quickly up to the required temperature, and the metal was therefore exposed to the heat for a rather shorter period than in the first case. Doubtless this accounts for the higher residue of lead and zinc noted in the second test.

These experiments show that at high temperatures the greater part of the iron is carried over with the zinc when hard zinc is distilled *in vacuo*. At a temperature of 500° C., however, the whole of the iron is left in the form of a non-

volatile residue, while zinc is obtained in the metallic state. If this process of refining were adopted on the large scale, there is no doubt that the consumption of fuel would be much diminished, while there should be no loss of zinc, as there is no possibility of oxidation. The necessary temperature is only just sufficient to render the metal visible in the dark, or in other words, it is a scarcely-visible dull red heat, so that in all probability unlined iron vessels might be employed for the distillation. The labour costs should be small, and when the apparatus was once in working order the great reduction in fuel consumption and in loss of zinc should render its working remunerative.

V.—THE EQUILIBRIUM OF THE COPPER-ZINC SERIES.

Hitherto experiments in the equilibrium of the copper-zinc series have been conducted at constant pressure, and the published diagrams are of this character. The experiments already described indicate that the conditions of equilibrium must vary greatly with changes of pressure, and open up a wide field of inquiry as to the effect of differences in the composition of the alloys and the variations in the pressure of zinc vapour. Particulars of a few preliminary observations in this direction may not be without interest.

In order to ascertain the approximate temperature at which zinc vapour begins to be evolved *in vacuo* a hard glass tube was taken, and into this was introduced some of the metal or alloy to be tested. The tube was then evacuated, until the pressure was less than that of 1 millimetre of mercury, and the tube was afterwards sealed. It was then placed vertically in an air bath so arranged that the lower part of the tube, which contained the metal, could be heated to the desired temperature, while the upper part of the tube was out of the air bath and kept well below the melting point of zinc. The air bath was then gradually heated until a deposit of zinc could be seen on the cool part of the tube. Proceeding in this way, it was observed that a deposit of zinc was produced in a few moments when zinc itself was heated to 375° C. With 60.40 brass, or "yellow metal," the

deposit did not form with any rapidity until a temperature of 520° was reached, while with 70 30 brass a still higher temperature, of about 550° , was necessary. By a modification of the experiment a piece of pure (Mond) zinc and clean pure (electrolytic) copper were introduced end to end in a horizontally placed evacuated tube, and then gradually heated in an air bath provided with a glass lid through which the progress of the experiment could be watched. The pieces of metal were arranged so as not to touch each other, and the whole of the tube was uniformly heated. It was observed that at a temperature of 380° C. the copper rapidly assumed a yellow colour. When thin sheet copper is acted upon, the brass coating is found to be quite firmly adherent and to stand polishing, or scratching with a knife, without change of colour. The resulting sheet brass is very soft and ductile. By prolonging the heating for about two hours sufficient zinc is absorbed to cause the copper to become first yellow, then redder in colour, and afterwards brilliantly white. It is therefore possible to prepare brass while the constituent metals are both in the solid state, through the absorption by the copper of the vapour emitted by the solid zinc. The action recalls to mind the ancient method of making brass, and the process of "sherrardizing" iron, the great difference being that the temperatures necessary *in vacuo* are so much lower, and there is no loss of zinc.

It will be seen therefore that at $375-380^{\circ}$ C. copper readily absorbs zinc vapour; at its melting point no zinc is retained; at 520° zinc vapour is given off by 60 40 brass, while 70 30 brass gives off vapour of zinc at about 550° . With more careful experiment probably these temperatures will be lowered, for it is stated that at about 184° C. faint indications can be obtained of the volatility of zinc *in vacuo* if the observation be extended over about fifty hours.*

Zinc vapour is quite colourless and transparent when in the hot evacuated glass tubes. Zinc can readily be distilled in glass vessels, and its close resemblance in appearance to the distillation of mercury makes the experiment very pleasing and interesting.

* E. Demarçay, *Comptes Rendus*, 1882, vol. xcv. p. 183.

SUPPLEMENTARY NOTE.

It may be added that since the foregoing was in type an abstract has appeared in *Nature* (December 7, 1911) of a paper recently communicated to the Royal Society by Mr. A. J. Berry, who has obtained a definite compound $MgZn_2$ by heating together magnesium and zinc *in vacuo*. Heycock and Neville had previously produced a definite compound $AuCd$ by heating gold with excess of cadmium in an evacuated hard glass tube to about the softening point of glass. The tube was bent over at one end, and this end was kept cool in order to condense the excess of cadmium.*

Tiede and Fischer have also quite recently effected a quantitative separation of lead from tin by heating *in vacuo* in a quartz tube in an electric furnace.†

* *Journal of the Chemical Society*, 1892, vol. lxi. p. 914.

† *Berichte*, 1911, 2, p. 1712.

DISCUSSION.

Mr. C. O. BANNISTER, Assoc.R.S.M. (London), in opening the discussion, said that it was quite interesting to note, from Professor Turner's figures, that a comparatively small quantity of tin and iron were volatilised. He would like to know if the author had any idea how the metals were volatilised—whether they were actually volatilised as metals, or were carried over mechanically, or as oxides. He did not think the author's suggestion for the refining of copper by the method referred to was likely to be carried out on a large scale, because electrolytic refining was very much more suitable, at any rate in most cases. The present was not the first time that vacuum treatment had been suggested for metallurgical processes. He did not know that it had been suggested for the treatment of metals, but it had certainly been suggested for the treatment of ores, such as the Broken Hill ore in the separation of lead sulphide from zinc sulphide. The chief difficulty in such work had been to obtain a suitable vessel which would withstand the outside pressure during the experiments, at any rate at high temperatures. With regard to the treatment of hard zinc, the apparently simplifying the process by decreasing the pressure was possibly more hopeful, especially as the author had shown that a high vacuum was not necessary in that case. It might, therefore, be possible to considerably simplify the method by slightly decreasing the pressure.

Sir GERARD MUNTZ, Bart., Past-President, said that when he first looked at the title of the paper he thought it was a most interesting one, but that probably the contents of the paper would not be of much use except in the laboratory; in other words, that it was purely a theoretical paper. As a practical man he put it low down on the list to be considered, but when he read it he changed his ideas. He thought the paper threw sidelights in many valuable directions. The point that had more especially struck him about the paper was that if the investigation was carried a little further it would be interesting and valuable in the following respect. In certain of the brasses with which the author had dealt the zinc had been entirely abstracted from the copper by the process used by Professor Turner, and had left the copper in the form of a residue. It would be very interesting if some of the scientific gentlemen who had proper apparatus could investigate the structure of the copper that was left, because he did not think any information was available at present as to what form the copper was left in as between the α and β alloys. The author had dealt with two brasses, one of which was an α alloy and the other a β alloy, from which he had abstracted all the zinc; and it would have an important bearing on the ultimate strength of metals for mechanical purposes to ascertain in what form the copper was left when the zinc was finally abstracted. Reversing the process, it struck him that it might be of interest, when the spelter was being absorbed by the copper at different stages, if an investigation were

made with a microscope to ascertain what the effect of crystallisation was in the metal. He asked the author on the previous day how deep the rezincifying of the copper had gone in the experiments, and Professor Turner replied that he did not think he had given sufficient time yet to get any great depth into the metal. At the same time it would be interesting to see what the crystalline form was in the resolution of the metals, because it happened to be a new line of research and investigation. With regard to the question of the practical utility of the process for manufacture, he was not at all sure that something could not be done in various directions at present, but the matter required very great consideration. The temperatures at which the absorption and evaporation took place were so low that he thought it was quite possible, especially with electrical furnaces, for the method to be put to practical use in various directions. The matter, however, required a great deal of consideration, and he had not yet had sufficient time to go into it to make any definite suggestions as to what might be done. But the chief point appeared to him to be the question of recrystallisation, and the question of the copper residue as left when the zinc had been volatilised.

Dr. WALTER ROSENHAIN, Member of Council, said that, in the first place, the results of Professor Turner's research suggests a possibility of a practical application of the method in the laboratory, namely, the possibility of considering distillation of metals *in vacuo* as a method of analysis. Investigators had certain metals to deal with analytically, particularly aluminium, which were extremely difficult to determine satisfactorily, as every chemist knew; but if vacuum distillation really gave quantitative results, it might simplify the whole of the process very considerably, so that the matter was very well worth studying. The determination of aluminium in aluminium-zinc alloys, for instance, had not proved practicable with any degree of accuracy by any method known at present, and the chemist had to confine himself to determining zinc and any known impurity, but he thought it would be possible to do the whole thing by a system of graded temperatures and separate receivers, and actually to separate the metals out in that way. He thought that was really feasible. The whole question of the volatility of metals was not only *in vacuo* at present, but in the air too. A great many people were working at the subject, and a great deal of work of the same kind had been going on at the National Physical Laboratory. The results were not ready for publication at present, but so far as they went they also gave interesting information. For one thing, the time required for any perceptible change of composition of an alloy when heated *in vacuo* was rather important from the point of view of the use of a quenching apparatus in which specimens were heated *in vacuo*. That had been tested, and it had been found that, after a reasonable time, the actual amount of change of composition was very small and confined almost to the surface at temperatures below the melting point. If one went on beyond that, he thought very considerable changes would be obtained, and careful consideration was required when that kind of apparatus was used. The general impression he had formed, quite apart from that

particular point, was that the volatility of metals was not altogether dependent upon heating them *in vacuo*; that, in fact, metals were almost as volatile in an atmosphere provided they were not coated with a protective coat of some kind. If a metal was coated with oxide and then heated, the space, which might be molecular in dimension, between the metal and the oxide coating rapidly became filled with saturated vapour, and this only diffused out through the oxide. That, of course, was a slow process, and consequently the ordinary volatilisation losses in heating metals in air were very slight. But if it was tested in a limited quantity of air, or *in vacuo*, or strictly neutral gas, then a considerable amount of volatilisation was obtained. He could have shown, if he had had an opportunity of bringing the specimens with him, a specimen of crystallised zinc obtained at 300° C. in a glass tube which had never been exhausted at all. It had been filled with hydrogen to prevent oxidation. Incidentally, the colder end of the tube became coated with a thick deposit of ordinary zinc crystals. That took place without the use of a vacuum at all. He did not suppose it took place as quickly as the result obtained by Professor Turner, but it did occur at atmospheric pressure; in fact, at a pressure higher than atmospheric, because the tube was filled at atmospheric pressure, and was then heated to 300° C. He did not wish to refer to any other point, except to venture a prediction on the question raised by Sir Gerard Muntz in regard to microscopic examination of brass from which the zinc had been distilled off. He had examined what was practically the brass formed by the action of vaporised zinc on copper, namely, sherardized articles, and those gave the range of structures of the ordinary brasses. It was practically the crystallisation of the copper which had absorbed the zinc with very little change indeed. On the other hand, with regard to the copper residue from the brass, he could not give any actual experimental evidence, but he would be very much astonished if anything else was found but simple pseudomorphs of what had been there before, just in the same way as if the zinc was removed by corrosion, pseudomorphs of the old structure were found. The zinc disappeared from it, and left behind a skeleton which was exactly like the crystals before, only it was not quite solid. The density would be lower. The author had brought forward a great deal of interesting matter in his paper, and he was sure the members hoped he would carry his experiments further, and that at a subsequent meeting he would favour them with some more valuable information.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), said that the author's paper was of great interest to him, chiefly for two reasons. In the first place, in the early 'eighties it so happened that he was engaged upon research work on high vacua in the manufacture of incandescent lamps. The volatilisation of metals *in vacuo* came prominently before him. The investigation was made for a London firm, *in camera*, so that publication was forbidden at the time. He would mention that it was observed that even platinum would vaporise in the vacuum of an incandescent lamp at a comparatively low temperature, so much so, that it was found necessary to reduce to a minimum the exposed area of the

platinum "leads" connecting the outside of the lamp to the little carbon globule, which members, no doubt, have noticed formed the attachment between the filament and the platinum conductor. Metals, such as copper and nickel, were tried, but found to be utterly useless; in a short time they were completely volatilised. He believed other workers engaged in the manufacture of incandescent lamps in those days made similar experiments, and came to the same conclusions, that it was impossible to expose any metal in a vacuum at even comparatively low temperatures without vaporising those metals. He did not wish it to be understood that those remarks detracted in any way from the paper that had been read; he only made reference thereto as a matter of interest. The second observation he wished to make was that the paper bore on some work he was engaged upon at the present time on the annealing of metals, a subject he had identified himself within the last few years. He had made a number of experiments to ascertain what was really an inert atmosphere, or an atmosphere that could be suitably used for regularly annealing metals without causing a volatilisation of the constituents to take place. In agreement with what Dr. Rosenhain had said, he found that it was quite easy to vaporise zinc out of brass at temperatures below its melting-point and at atmospheric pressure by means of a stream of gas. Both hydrogen and nitrogen were effective in that respect. He had found, however, that a mixture of gases prevented, or largely prevented, such a result, due probably to reversible action taking place at annealing temperatures. In that direction he had been working for some years. In regard to copper, the author stated in his paper that it required something like 1200°C. to distil that metal *in vacuo*. In the course of the experiments he had made, employing hydrogen gas, he found that copper was distilled easily at between 700° and 800°C. ; so much so, that he had covered pieces of iron in a tube with copper by simply placing a piece of copper near it, passing a stream of hydrogen gas first over the copper then over the iron, heating both to, as nearly as possible, an equal temperature in an electrical furnace. A pyrometer inserted at the centre of the furnace indicated a temperature of about 700°C. In connection with the subject of poisoned brass, and the curious observations of an Indian writer referred to by the author, he could not help connecting Mr. Bengough's mechanical abuse of brass and other metals, and their "cry" or squeal he heard. That alloys or metals might be improved in quality by heating in suitable atmospheres without reducing the pressure was established by his own experiments.

Mr. H. M. RIDGE (London) said there was a certain amount of analogy between the proposals described in the paper and the experiments which had been done on a large scale in Germany a number of years ago in connection with the reduction of zinc ores. In the ordinary zinc distilling muffles an appreciable pressure was produced in consequence of the reduction of zinc oxide by carbon forming two gaseous products, viz. zinc vapour and carbon monoxide, and the pressure due to the increased volume causes considerable loss of zinc by leakage through the more or less porous clay retorts. Much effort has been

expended in attempting to avoid this loss, and part of the difficulty is overcome by glazing the retorts. If he remembered right, experiments were done in Silesia, at a time when almost only calamine was treated there, to reduce the pressure inside the retort by connecting the condensers to an air-pump. These experiments were carried on for many years, but finally dropped owing to mechanical difficulties. He only wished to draw attention to these facts as matters of detail, which would necessarily occur in connection with the removal of zinc as suggested by the author, but the technological advances made in the last few years may make it possible to overcome the previously insurmountable obstacles. He was sorry to find that the author despises zinc to such an extent as to consider it a thing requiring removal, and he wished to inquire whether it would not be possible to look at the question in a different light, namely, for recovering instead of destroying the zinc. Quite apart from the question of adapting the new method for use in connection with the production of spelter from the zinc ore, there appeared to be possible scope for the process in connection with the refining of spelter. At the present moment experiments were being made in Norway for the treatment of zinc material in electrical furnaces in order to obtain a high-grade spelter, but this had to be done in two or three separate stages. The first distillation did not yield a marketable spelter; it produced a product high in lead, and mixed with a certain amount of oxide and zinc dust, so that it had to be redistilled at least once, and sometimes twice. It struck him that possibly the author's vacuum might be a means of overcoming that trouble, and he wished to suggest whether the author would not be able to devise means of refining some of the spelter at a comparatively low temperature, and thus removing lead and other impurities. The quantity of material now being redistilled was so very large, and there was such considerable scope for improvements in the present methods, that he thought a further series of experiments should result in valuable information being gained, and should be of considerable benefit to manufacturers.

Professor TURNER, replying to Mr. Bannister's question as to how the metals were volatilised, whether in the form of oxide, or by a stream of gas, or in some other way, said that as the metals were *in vacuo*, they were volatilised as metals without any stream of gas, and without any oxidation. Mr. Bannister suggested that the electrolytic treatment would be better for crude coppers; but that was not the case for crude coppers such as he (the author) had in view, and which might contain relatively large quantities of antimony, arsenic, tin, lead, and sundry other things. If electrolytic treatment was adopted, it would be found that the depositing tank would soon be filled up with sludge. He only suggested the method as being applicable for very crude coppers, and those crude coppers must be refined in some way before they could be electrolytically treated. Mr. Bannister also said there would be a difficulty in obtaining a vessel which would stand a vacuum at the high temperature required. For the refining of the zinc he only worked at 500° C., and there was no great difficulty in finding a vessel which would stand a

vacuum at a temperature of 500°C . In all the other cases where he suggested a higher temperature should be used, there would be a separate outside containing vessel which would not be heated at all, so that he thought that difficulty would not arise—at least he hoped it would not. Dr. Rosenhain gave some very interesting information, and referred to the time taken for distillation. Under ordinary pressure the time taken for distillation was comparatively prolonged, but, as he mentioned in the paper, the time taken for the observations was only three-quarters of an hour for the separation *in vacuo* of the quantity used in the experiment. Three-quarters of an hour was probably well above the time necessary for separating the metals, but it had been adopted in order to get rid of the last trace, so as to ensure a quantitative result. Using an electric furnace and the proper current, the right temperature was certain to be obtained, and in three-quarters of an hour the experiment was complete. Mr. Vaughan Hughes raised the question of the temperature which was required in the distillation of zinc from copper. He mentioned in the paper that the temperature was taken at 1200°C ., and Mr. Vaughan Hughes referred to that as being high. It would not require 1200°C . on the large scale to separate zinc from copper. A temperature of 1200°C . was only required to get a rapid and definite quantitative separation. A great deal of the zinc could be got off below that temperature, but to get the last trace off so as to get a quantitative result, it was necessary to just melt the copper. He had been very much interested in Mr. Ridge's remarks on the practical application of the processes. He naturally supposed, in the first instance, that the vacuum process might be applicable to ores. He tried to experiment by heating zinc oxide in contact with charcoal *in vacuo* at various temperatures, and found there was very little advantage in the use of a vacuum under those circumstances. The reason was that the reduction of oxide of zinc took place at about 1050°C ., and zinc boiled, as was well known, somewhere under 960°C . under ordinary pressure, and of course at considerably lower temperatures at reduced pressures. Since it was necessary to raise the oxide of zinc to its reducing temperature before the reduction could take place, there could be comparatively little advantage in the application of reduced pressure to the treatment of ores, and he was not surprised to find that, although there would be some advantage, it had not been sufficient to make the process pay. Mr. Ridge also referred to the complex zinc products that were now being obtained in Norway, and personally he (Professor Turner) had little doubt that the vacuum process could be adopted in dealing with such alloys with very great advantage. He did not, however, propose to separate zinc from lead by means of distillation, except, perhaps, in special cases, because zinc and lead could be so easily separated. It was only necessary to melt them and allow them time to separate, and that was the cheapest and simplest plan, unless special purity were desired. He would separate as much lead as possible, and then distil the product. He wished to say, in conclusion, that he had very considerable confidence that there was a future for the application of vacuum separations as commercial processes for the treatment of metallic mixtures. He would not propose to drive

off the zinc, and regard it merely as a by-product, or something to be got rid of. He believed that the monetary results of the processes would often depend on the extraction of the zinc.

COMMUNICATIONS.

Mr. H. I. COE, M.Sc. (Birmingham), wrote that Professor Turner's interesting paper must have an important commercial application, not only in the purification of brass, but in many other operations where it was necessary to separate zinc from associated metals.

When a thorough knowledge of the vapour pressures of zinc at different temperatures, and also of other metals, such as lead and tin, had been obtained, a wide field might be opened up for further application of Professor Turner's experiments; for example, the products after the desilverising of lead by zinc might be treated *in vacuo*. The construction of suitable apparatus ought not to present serious difficulty. He was most interested, however, in Professor Turner's remarks with reference to vapour pressure and the equilibrium of the copper-zinc series of alloys, and he trusted that by this means further light would be thrown on some points still in doubt.

Mr. H. J. HUMPHRIES (London) wrote that it had occurred to him that one of the most promising directions in which Professor Turner's process might be applied to practical work would be the distillation of zinc scums from the Parkes' process, as was indicated in Professor Turner's remarks at the meeting. He desired, however, to ask whether the author could say, from the experiments already carried out, if it would be possible to distil over all the lead and leave the silver, or would the silver be likely to follow the lead? Of course if one stopped at the distillation of zinc, the process might still be of considerable value, as apparently it could be conducted in iron vessels and the not inconsiderable cost of graphite retorts eliminated.

Mr F. JOHNSON, M.Sc. (Swansea), wrote that he greatly appreciated the paper, and congratulated Professor Turner on having foreseen the possibility of putting the results of his investigations to practical use. Whatever might be the difficulties in the way of a practical application, the author's suggestions were excellent. The refining electrolytically of some kinds of impure copper was, for more reasons than one, out of the question, and if such material could be refined by a commercially successful vacuum distillation method, the industry of the non-ferrous metals would be largely benefited.

The writer had previously shown that bismuth was distilled off from copper in a reducing atmosphere (hydrogen gas), and if that could also be effected *in vacuo*, then there would be an additional application open for Professor Turner's suggestion. To do that, and make it a commercial

success, however, it would be necessary to deal with several tons of metal at a time.

Another useful application would be in the treatment of fine brass filings, borings, and turnings, which lost a considerable amount of metal when melted down in the ordinary way in crucibles or in an open type of furnace, especially with insufficiently skilled workmen. Such material, treated in a vertical receptacle, such as a crucible or in a horizontal retort, should be subject to very little loss at all if treated by Professor Turner's suggested method. It would be a great advantage if Professor Turner would give a sketch of the apparatus employed.

Professor TURNER, in further reply to the inquiries of Sir Gerard Muntz, wrote that as the copper was in the fused state after the zinc was removed from brass, a microscopic examination would, unfortunately, not yield information as to the form in which the copper was left from the different phases. When copper was heated in zinc vapour a microscopic observation showed that the interior consisted of unaltered copper; this was surrounded by a layer of yellow brass, which appeared to be the ordinary *a* constituent; with longer heating in zinc vapour a white brittle outer layer was formed of a phase richer in zinc. There were thus three distinct layers which were separated from each other by sharp lines.

Further tests had not confirmed the loss of arsenic when copper was melted *in vacuo*. Either the result was exceptional, or an error arose owing to the small quantity of the residue which was available. The rule appeared to be that any quantity of arsenic under about 20 per cent. remained in the copper; antimony remained with the copper up to nearly 39 per cent. (Cu_3Sb); with bismuth, on the other hand, as much as 25 per cent. could be readily removed by melting *in vacuo*. He hoped to publish particulars of these tests shortly.

In reply to Mr. Humphries, Professor Turner wrote that zinc could be removed from silver-zinc scums by heating *in vacuo* at 700°C ., at which temperature the volatilisation of silver was very small, but some lead was removed. At higher temperatures more lead was carried over, and the silver losses increased.

In reply to Mr. Coe's remarks, some further tests had been made on the equilibrium of the zinc-copper series *in vacuo*, but the investigation presented many difficulties, and had various ramifications, so that a good deal of careful work would be necessary if any results of value were to be obtained. The remarks of Mr. Johnson in reference to the removal of bismuth from copper by heating in hydrogen were interesting, and were in accordance with what was above stated, since when starting with a special alloy containing 75 parts of copper and 25 of bismuth the quantity of bismuth left in the copper after heating *in vacuo* at 1200°C . was so minute as to be scarcely detected by the lead iodide colour test. Fig. 1, p. 122, shows the arrangement of the apparatus used by Messrs. Cartland and Grove in these experiments, and it was hoped that that would give the information desired by Mr. Johnson.

In order that trials might be conducted on the commercial scale,

provisional protection had been obtained for the processes of separating or refining metals and alloys by heating *in vacuo* or under reduced pressure, and arrangements had been made whereby two firms would be interested, one dealing with hard spelter, and the other being concerned with zinc containing silver or gold.

The alloy to be examined is placed in a porcelain boat, or in a closed glass tube, according to the object of the experiment. It is heated in a porcelain tube in an electric furnace of the resistance type (A). The temperature of the tube furnace is observed by means of a thermocouple, of which the cold junction is shown at B. At one end the porcelain tube is covered with a glass plate (C), which is sealed with sealing-wax, and

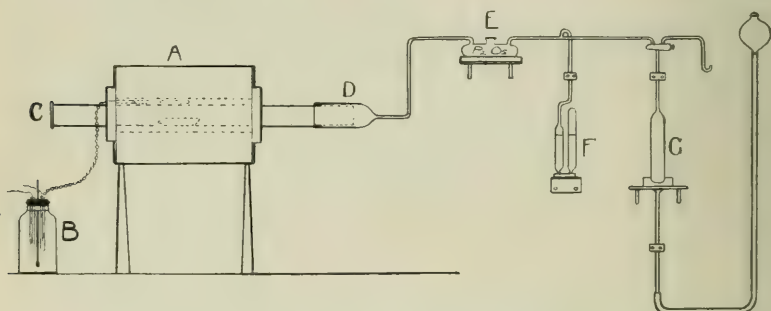


FIG. 1.—Apparatus employed for heating Alloys *in Vacuo*.

- A=Electric resistance furnace, with porcelain tube and boat.
- B=Cold junction of thermocouple.
- C=Glass end plates with sealing-wax joint.
- D=Glass reducing piece, with sealing-wax joint.
- E= P_2O_5 drying tube.
- F=Mercury pressure gauge.
- G=Mercury pump, with three-way tap.

which provides for the inspection of the sample during heating. At the other end a glass reducing piece (D), with a sealing-wax joint, connects the porcelain tube to the rest of the apparatus. A drying tube (E), containing P_2O_5 , absorbs moisture, while the pressure is ascertained by means of a shortened mercury gauge (F). The apparatus is exhausted by the use of a simple form of mercury pump (G), which is provided at the top with a three-way tap. The gases drawn off from the apparatus may, if desired, be collected and examined. There are no rubber connections, and no grease is used, except a small quantity, of a special kind, for the three-way tap. By such an apparatus it is possible, in a few minutes, to obtain an exhaustion corresponding with a pressure of 1 millimetre of mercury or less, and this does not appreciably alter during a period of twenty-four hours.

A STUDY OF THE PROPERTIES OF ALLOYS AT HIGH TEMPERATURES.*

BY G. D. BENGOUGH, M.A. (THE UNIVERSITY, LIVERPOOL).

INTRODUCTION AND HISTORY.

THE determination of the changes in physical properties which take place in metals and alloys as the temperature is raised has attracted the attention of comparatively few workers. This is true even in the case of iron and steel, and is more remarkable still in the case of non-ferrous metals and alloys. Yet the subject is one of considerable interest, both from the practical and the scientific point of view. In practice non-ferrous metals or alloys are sometimes called upon to withstand the combined effects of heat and stress, as in the case of the sheets and stays of locomotive fireboxes; also in the case of certain valves and other engine parts, though here the temperature conditions are less severe. Further, a study of mechanical properties at high temperatures should throw some light on the behaviour of metals and alloys when forged or rolled, and might be expected to offer some interesting suggestions as to the best limits for rolling temperatures.

From the scientific point of view, the correlation of mechanical properties with phase relationships should prove a study of considerable interest.

In the case of copper alloys one of the earliest researches carried out on any considerable scale was that conducted by the Admiralty at the Portsmouth Dockyard in 1877. The test-bars were heated in an oil bath, and then transformed rapidly to a tensile testing machine and broken. It was claimed that the whole operation only lasted a minute, and that, in consequence, the temperature errors were not serious.

The results obtained were remarkable, and showed a sudden and big fall in tenacity at temperatures between 350° and

* Read at Annual General Meeting, London, January 17, 1912.

400° F. in the case of bronzes containing from 5 to 9.75 per cent. of tin, and from 10 to 2 per cent. of zinc. A copper-zinc alloy, containing 62 per cent. of copper, was also tested, but showed no such sudden drop in strength.

In 1890 Martens* published an elaborate investigation on the mechanical properties of iron and steel at high temperatures, and included copper in his tests. For temperatures up to 200° C. his bars were heated in a bath of paraffin; between 200° and 600° C. in a bath of lead or lead-tin alloy; in both cases, jets of gas were used for heating the bath. Temperatures up to 400° C. were measured by a mercury thermometer; temperatures above 400° by an air thermometer, which caused much trouble.

In 1899 Unwin† re-investigated the whole matter. His apparatus consisted of a special horizontal testing machine of the manometer type, the pressure on the diaphragm being balanced by a mercury column. The bars were turned down to a diameter of a quarter to five-sixteenths of an inch, and elongation was measured over a 2-inch length. The bars were placed in an oil bath heated from below by a gas burner, and placed between the jaws of the testing machine; the temperature of the oil bath was taken by means of a mercury thermometer. Fig. 1 shows Unwin's arrangement; he states that above 600° F. (= 316° C.) the thermometer behaved irregularly. The highest temperature used in the research was 340° C. Some of his results are shown in Table I.

In 1900‡ Le Chatelier published a number of tests at high temperatures. His results for pure copper are given in Table I., and are plotted in Figs. 6 and 7, together with the author's. The similarity between the two sets of maximum stress results is remarkable.

Webb§ has published the results of a large number of tests on many different alloys at comparatively low temperatures. His principal object was to determine the best alloy to use for the stays of locomotive fire-boxes, and his paper is the standard work on the subject. Only a few of his tests are comparable

* *Mitteilungen aus den Technische Versuchsanst zu Berlin*, 1890, p. 159; also *Proceedings of the Institution of Civil Engineers*, vol. civ. p. 209.

† *Report of British Association*, 1899.

‡ *Congrès des Méthodes d'Essais*, Paris, 1900.

§ *Proceedings of the Institution of Civil Engineers*, vol. cl. (1901-2).

with those of the author, owing to the different ranges of temperature in which they worked.

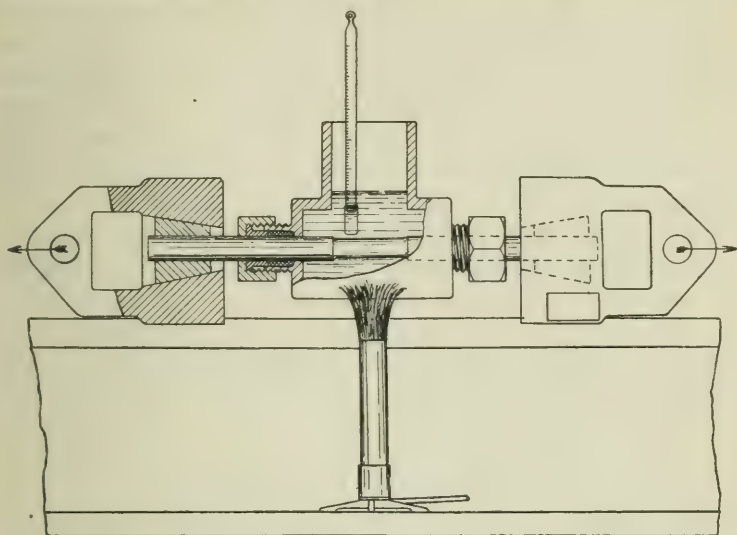


FIG. 1.

In 1907 Rosenhain, and in 1910 * Rosenhain and Lantsberry, published the results of some high temperature tests on copper-aluminium alloys, with and without manganese.

TABLE I.—Copper (Rolled).

Atmospheric Temperature.	Tenacity, Tons per Square Inch.		Elongation on 2-inch Per Cent.	
	Le Chatelier.	Unwin.	Le Chatelier.	Unwin.
Degrees Centigrade.	15.0	17.8	42.0	10.0
100	...	17.4	...	9.0
110	12.9	...	41.0	...
149	...	16.4	...	8.0
200	11.4	...	36.0	...
210	...	15.9	...	9.0
260	...	15.1	...	7.0
316	...	14.3	...	4.0
316	...	14.2	...	5.0
330	9.6	...	34.0	...
340	...	13.7	...	4.5
430	8.1	...	17.8	...
530	4.6	...	16.4	...

* *Proceedings of the Institution of Mechanical Engineers*, January 1910.

The apparatus used on both occasions consisted of a small electric resistance furnace placed between the jaws of an ordinary testing machine. Temperatures were measured by a thermocouple. The degree of uniformity in heating was ascertained with much care, a matter that had been rather neglected by some of the earlier workers. A special series of observations showed that no differences of temperature exceeding 5°C . could be detected in a $2\frac{1}{2}$ -inch length of the specimens, even at temperatures as high as 500°C .

In 1911 Hughes published in this *Journal* the results of some experiments on copper at high temperatures, and figured his apparatus. It resembles Unwin's, except for the facts that the test-bar is held vertically instead of horizontally, and that an air space is introduced between the oil bath and the test-piece. The highest temperature employed was 350°C .

SCHEME OF PRESENT RESEARCH.

The original scheme for the present research was a somewhat extended one. It was divided into two parts. In the first place, it was desired to make a considerable number of tests, under strictly comparable conditions, of the properties of copper-rich alloys of the following binary series, all of which have been employed at one time or another to withstand the combined effect of stress and temperature—copper-arsenic, copper-nickel, copper-manganese, and copper-vanadium. In the next place, it was proposed to take one or two pure metals, and also selected materials from some well-known series of alloys, the constitution of which had been satisfactorily established, and to construct typical curves for all types of single-phase and two-phase systems. As regards the alloys, it was thought that the series most likely to give interesting results would be one in which the industrially usefully alloys extended over a sufficient range of composition to include both single-phase and two-phase systems, and for this reason, amongst others, the copper-zinc series was chosen.

Work was begun on both parts of the scheme, but it soon became clear that it would be necessary to modify it considerably, since it was found necessary to investigate a number of

subsidiary matters about which no information could be obtained from the literature on the subject. One of the most important of these matters was the influence of the *time under stress* upon the strength and ductility. At ordinary temperatures this factor has little effect in the case of static stress, but as the temperature of the test-bar is raised it soon becomes of considerable importance.

The section of the research now published is confined entirely to the second part of the scheme outlined above, and the only properties discussed are the maximum stress, elongation, and contraction of area under static tension.

DESCRIPTION OF EXPERIMENTAL METHODS.

Rather full descriptions will be given under this head, for the reason that, so far as the author has been able to ascertain, the present paper contains the first account of an attempt to follow the variation of mechanical properties from the ordinary temperature up to the melting points of the respective metals. Practically all previous workers, Rosenhain and Lantsberry excepted, have stopped their experiments at temperatures not higher than $350^{\circ}\text{C}.$; Rosenhain stopped his at $450^{\circ}\text{C}.$, except in one experiment, when a temperature of $500^{\circ}\text{C}.$ was used.

The apparatus in this research may be conveniently considered under two headings:—

- (1) The methods of heating and measuring the temperature of the specimens under test.
- (2) The methods of applying and measuring the stress and strain on the specimen.

(1) *Method of Obtaining and Measuring Temperatures.*—The earlier workers, including Martens, Unwin, and Hughes, heated their specimens in baths of oil or molten metal, and measured the temperature of the bath by means of mercury or air thermometers. In this type of apparatus it is obvious that the temperature must increase from the bottom of the apparatus upwards, and this will give rise to considerable variation in temperature throughout the bath. This is especially the case when the bar is placed vertically, as in Hughes' apparatus. There is a

further possible source of error in both cases due to the fact that the thermometer measures the temperature of a point in the bath, and not of the metal itself. Owing to the lack of stirring apparatus, and to the difference in thermal properties (conductivity, radiative power, &c.) between the bath and the heating liquid, it is by no means certain that they take exactly the same temperature when the whole has come to thermal equilibrium. There will probably be a constant though small difference in temperature between the bar and the liquid. Both the errors mentioned become rapidly more significant as the temperature rises, and seriously vitiate all results at temperatures above 350° C. At 400° C., in an apparatus similar to that figured by Hughes, the author found a difference in temperature of 45° C. between the top and the bottom of a $2\frac{1}{2}$ -inch gauge length. Unwin and Hughes, however, carried out most of their experiments at comparatively low temperatures—below 350° C.—and the horizontal position of Unwin's bars lessened materially the chances of error in his case.

From what has been said, it is obvious that the only sound method of experiment is to use an electric resistance furnace of which the thermal gradient has been made as uniform as possible, and to measure the temperature by thermocouples kept in actual contact with the test-bar itself. It must be borne in mind that the work of Martens and Unwin was carried out before the thermocouple had come into general laboratory use for experimental work.

Rosenhain and Lantsberry give the following details of their apparatus and working accuracy. The heating apparatus was a nickel wire resistance furnace used in a vertical position between the jaws of a testing machine. At first they found differences of from 10° to 30° C. between the top and bottom of their specimens; later, they were able, by carefully adjusting the packing of the lower portion of the furnace, to counteract this tendency of the upper part to attain a higher temperature, and finally they state that even at a temperature of 500° C. no differences exceeding 5° C. could be detected in the length of the specimen ($2\frac{1}{2}$ inches).

The present author has used a vertical resistance furnace wound with platinum strip, and has been able to approach,

but not quite to equal, this degree of uniformity. In some preliminary experiments two thermocouples were used, and the junctions were tightly wired on to a bar hung vertically in the furnace at a distance of 2 inches from one another, each junction being at a distance of 1 inch from the centre of the bar. The following results were obtained:—

Top Couple, Degrees Centigrade.	Bottom Couple, Degrees Centigrade.	Difference, Degrees Centigrade.
240	216	24
342	323	19
424	404	20
510	490	20

To improve these results, loose asbestos packing was introduced into an air space between the outside lagging of furnace and the platinum winding; also, into the centre tube of the furnace around the test-bar itself. After some trials the following improved results were obtained:—

Top Couple, Degrees Centigrade.	Bottom Couple, Degrees Centigrade.	Difference, Degrees Centigrade.
292	286	6
348	340	8
480	485	5
521	514	7
610	616	6

It will be noticed that in all cases the temperature of the top couple was slightly higher than that of the lower; this difference was so slight, however, that though fracture of the test-pieces took place more frequently in the top half of the gauge length than in the bottom half, there were but few occasions in which it occurred either on or above the top gauge mark. When this occurred the results have not been recorded in the tables and curves.

The experiments just mentioned were carried out with the Carpenter-Stansfield potentiometer and platinum-iridium couples. All temperature measurements in the actual tensile experiments were carried out with the same couples and a thread recorder, which was particularly useful in showing

graphically when thermal equilibrium had been obtained in the bar. The degree of accuracy of the temperature measurements with this instrument was not greater than $\pm 4^{\circ}$ C. It should be mentioned that it is absolutely essential that the thermo-junction be in actual contact with the test-bar. The temperature of the heating element in the type of furnace used is always higher than that of the bar, and the temperature of the intervening space is also somewhat greater than that of the bar, even at points quite close to the latter. This arises from the fact that the thermal properties of the bar under test were different from that of the surrounding air space.

(2) *Methods of Applying and Measuring Stress.*—It was highly desirable to instal permanently the heating and temperature measuring apparatus, owing to the large number of tests which it was proposed to carry out. This apparatus was somewhat bulky, and could not be conveniently fitted to the Liverpool University tensile testing machine; it was therefore decided to design a special piece of apparatus for carrying out the tests. On the ground of expense it was advisable to keep it as simple as possible, and to do away with the use of levers for magnifying the load applied to the specimen. Plate XIV. is a photograph of the apparatus used in the part of the research now published, and which it assumed after a number of preliminary trials. Figs. 2 and 3 give drawings of details. All three are lettered to correspond with one another. In Fig. 2 it will be noticed that the test-bars are all screwed at the ends and fitted into extension pieces, which in turn are screwed into hemispherical nuts. These nuts are carried on spherical seatings, which rest on asbestos pads. The pads are placed on carriers attached respectively to the top framing of the machine and to a steel stirrup carrying the weights. The asbestos pads are used to lessen the amount of heat lost by conduction to the various parts of the machine.

The top carrier, with its seating, can be moved horizontally in two directions, and can thus be accurately adjusted so that the top seating is vertically above the lower. This adjustment is of great importance owing to the well-known fact that the efficiency of spherical seatings is very small with small loads.

The load is applied to the specimen by placing weights on

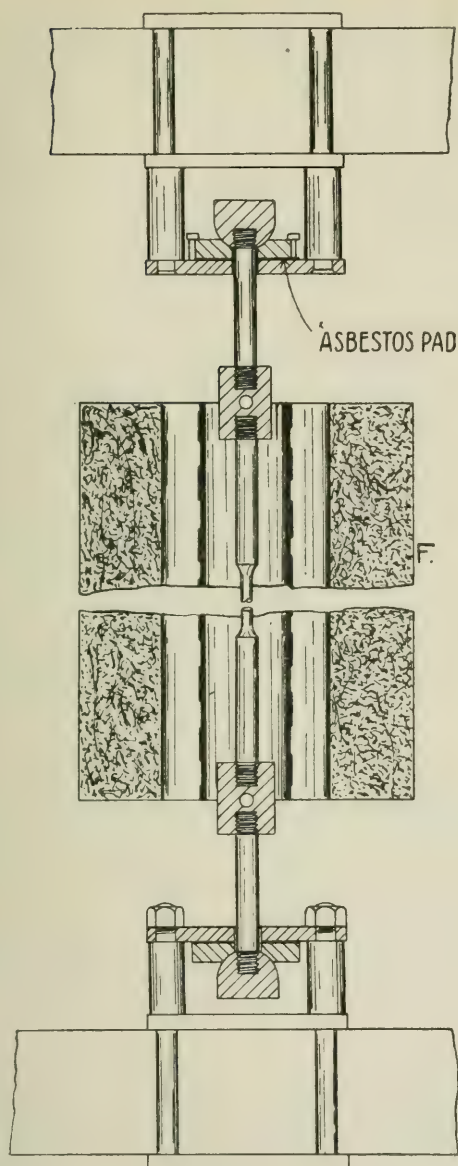


FIG. 2.

the stirrup. In Plate XIV. nine weights of 56 lbs. each are shown on the near side of the stirrup; additional weights can be built up on these to the required amount. A similar load can be applied to the other side of the stirrup. The

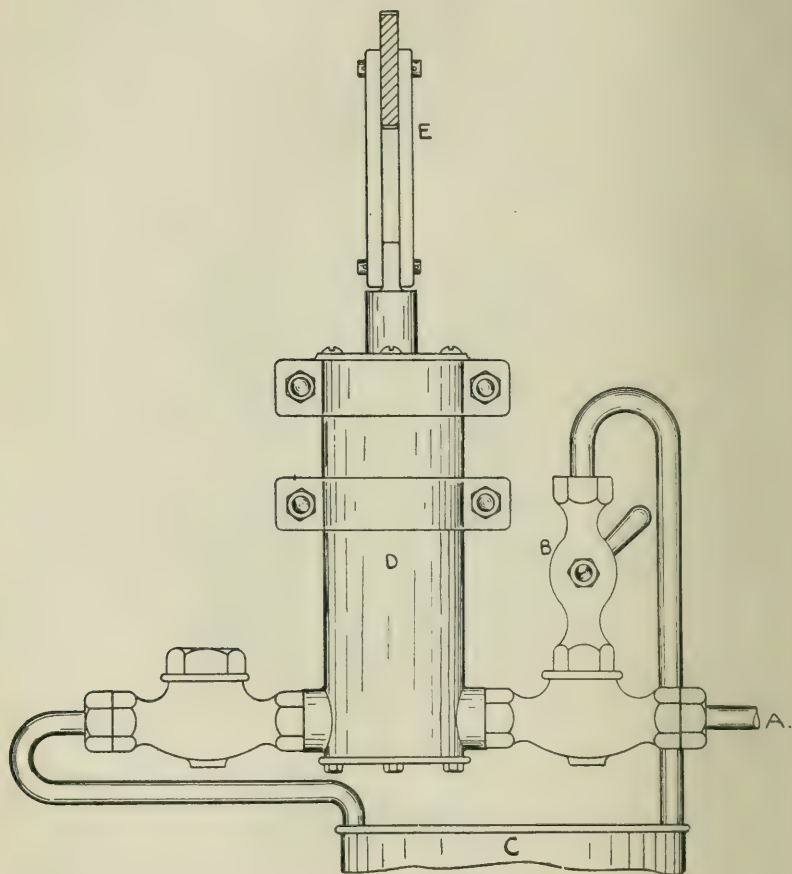


FIG. 3.

stirrup, weights, and seating hang from the spherical nut attached through the extension piece to the lower end of the specimen. Lateral play of the stirrup is limited by rollers which were placed at each side of it, and worked between the two L-shaped girders, which form the upright framing

of the machine. There is about a quarter of an inch play between the rollers and the framing at each side.

The maximum load which the machine is designed to carry is 2 tons, and some arrangements had to be devised to take up this load when the specimen broke. It was also most important to arrange that when a weight was added, the additional stress could be applied to the test-bar gradually, and without impact. Both these conditions were met by the use of a hydraulic ram and cylinder. This device cushions the load after the fracture of the specimen, by allowing the stirrup to fall only as fast as the ram to which it is attached can drive water out of the cylinder through a pipe of very small section. The hydraulic ram is seen in Plate XIV., also the top of the cylinder, showing white amongst the weights. The top of the ram is riveted to the cross-bar of the stirrup; after the fracture of a specimen the ram sinks owing to the load on the stirrup, and drives liquid from the bottom of the cylinder through pipe A and tap B into the copper reservoir C. But this can only occur when tap B is open; when it is closed no liquid can leave the cylinder. Hence any small additional load applied to the stirrup is not transmitted to the test-bar, since this load is merely employed in compressing the practically incompressible liquid in the cylinder. It follows that by slowly opening the tap B the load can be applied to the test-piece as gradually as desired, and without any appreciable impact. After again closing tap B the load remains on the specimen, but no additional load placed on the stirrup will be transmitted to the specimen; in other words, the valves do not allow of back suction.

The arrangement of the valves and of a pump to allow of the stirrup being raised to the required position for attachment to the spherical nut is shown in Fig. 3. The pump D raises liquid from reservoir C, and forces it into the hydraulic cylinder, provided the tap B be closed. Plate XIV. shows the position of the cold junctions of the two thermocouples X and Y. Behind the machine can be seen the thread recorder Z.

The effective load of the stirrup, that is, its real weight minus the frictional effects of the various parts of the machine, is ascertained by means of a carefully calibrated spring balance.

Frequent check tests have shown that the effective load remains constant for long periods of time. The spring balance gave scale readings from 4 lbs. up to half a ton, and this range was useful in calibrating the machine for small loads. It was found, however, that the actual load on the specimen was sufficiently accurately expressed by the effective load plus the value of the weights used. In all cases the weights were arranged quite symmetrically with regard to the hydraulic cylinder; this was thought to be desirable in order to avoid any slight tilting effect which might occur in spite of the long bearing of the ram in the cylinder.

Attached to the lower part of the right-hand pillar of the machine (Plate XIV.) is seen an electric bell. This is put into action by the fall of the stirrup, and is useful in the experiments of the effect on maximum stress of the time under load.

The furnace, marked F, is seen in the centre of the machine; it is so arranged that it can be swung out on a hinge near the pillar. This adjustment was found to be very useful in introducing and removing the test-bars.

The loads actually used in the experiments varied from nearly 2 tons down to 7 lb. This last was much smaller than the effective weight of the stirrup alone, which was, in fact, nearly 1 cwt. For loads smaller than this separate arrangements had to be made. The stirrup was let down to its lowest position, an oak board was then screwed on to the top of the carrier, and on to this was placed a flat, light scale pan of special construction, which weighed only 3 lb.; by working the pump the scale pan could be raised and attached directly to the extension piece in a simple manner. Weights could then be placed on the pan in amounts sufficient to cover the whole range of loads from 3 lb. to 1 cwt. At the beginning of the test the stirrup was lowered slightly, and the scale pan was left hanging freely from the extension piece. When fracture took place the scale pan fell on to the oak boards. The height of this drop could readily be kept very small, by adjusting the height of the ram in the cylinder by hand-pump and tap, so that it followed closely the extension of the test-piece. For very small loads a water-load, which could be increased at a slow but constant rate

by means of a tap, was used. The water was run into two vessels simultaneously, the vessels being placed symmetrically upon the pan.

This machine is described as it was used in the present research; it is undergoing certain improvements and modifications, partly to allow of a reducing or neutral atmosphere being maintained in the furnace, and partly to allow of tests other than those now described being carried out with it.

The machine has been made for the author by Mr. W. W. Strafford, of Crosby, Liverpool, and has given complete satisfaction in use.

PRELIMINARY EXPERIMENTS.

All the bars used in the research could be broken in the machine at the ordinary temperature, with the exception of the $\frac{1}{2}$ -inch cast bars. Some comparative tests for bars broken cold in the machine described, and in the ordinary tensile testing machine, are given in the tables of results on pp. 142 *et seq.* The two sets of results agree about as closely as the pairs of tests with the ordinary machine, and the results as a whole are as satisfactory as can be expected when the well-known difficulty of getting closely agreeing results with non-ferrous metals and alloys is borne in mind.

Except where the contrary is stated, all the tests were carried out on $\frac{1}{2}$ -inch round bars turned down parallel to a $\frac{1}{4}$ of an inch diameter over a length of $2\frac{1}{2}$ inches, in the case of all the rolled bars. The cast bars were 1 inch in diameter turned down to $\frac{1}{2}$ inch for $2\frac{1}{2}$ inches.

One of the difficulties of the research was to find a suitable method of marking the bars for the purpose of measuring elongation. The ordinary method of punch marks was quite unsuitable for small bars at high temperatures, and localised the fracture at once. In any case it would have been useless owing to oxidation. A large number of alternative methods were tried, and from them the following were selected as giving the best results under the conditions stated.

1. *Marks of Graphite.*—These were suitable for brass alloys up to a temperature of about 600° C. They were sufficient

for all the aluminium bars. In the case of copper and copper-nickel bars they were only suitable for comparatively low temperatures. It may be mentioned that some kinds of copying pencil give remarkably good results for moderate temperatures. In some cases a complete ring of deposit was made round the bar and for some distance outside the gauge length towards the shoulder, with the object of limiting oxidation. The junction between the oxidised and protected parts could then be clearly seen.

2. *Heavily Gold-plated Marks.*—The bars were plated from shoulder to shoulder with a thick deposit of gold. The middle 2 inches of the parallel portion was then “buffed” free of gold. The gold prevented the oxidation of the bar beneath it, and a sharp line of demarcation was obtained between the plated and the oxidised surfaces. This method was useful for brass up to a temperature of nearly 800°C . It was not so satisfactory for the copper-nickel bars, which scaled so heavily that the plating flaked off in an irregular manner at the edges. These bars were the most difficult to mark, as the scaling was even worse than with pure copper except at the highest temperatures.

3. *Method of Fireclay Wedges.*—This method was based on a chance observation that fine tinned copper wire used for tying the thermocouples on to the test-piece held very tightly to the fine grained fireclay tube by which the wires of the couple were insulated from each other. This appeared to be due to the formation of a trace of silicate of tin, but the cause was not investigated in detail. The method of marking based on this observation consisted in making two little fireclay wedges and tying them on to the specimen with the tinned wire; the wedges pointed towards the centre of the bar, as this was the most likely direction of slip in the case of a drawn-out bar. The friction due to the oxidation of the test-bar kept the little wedges in position, and the distance between the wire ties was measured before and after the experiment. This method failed in the case of metals which drew out very greatly, as, for instance, in the case of certain complex brass bars which gave elongations up to 165 per cent.

4. *Method of Shoulder Measurement.*—In cases in which all

the above methods failed, resort was had to the method of shoulder measurement. This method is admittedly only approximate. It consisted in making a test-bar of such a form that exactly 2 inches of it were parallel; beyond this the diameter was gradually increased up to the shoulder, which was $\frac{1}{2}$ an inch beyond the parallel portion on each

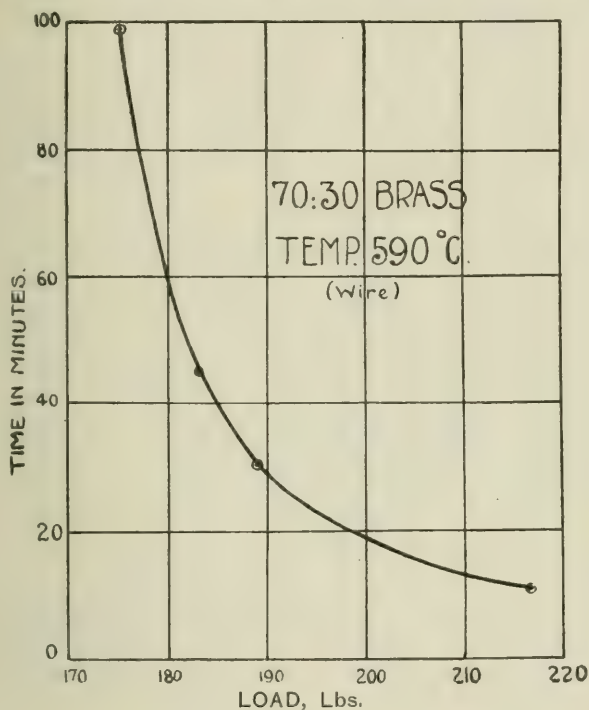


FIG. 4.

side. The total elongation between the two shoulders (which were 3 inches apart) was then measured, and the total elongation calculated on to the 2-inch length, the assumption being made that no elongation took place over the gradually enlarged part of the bar. This is probably true in most cases, and the author believes that the errors of this method consist in the fact that the near neighbourhood of the enlarged shoulder diminishes the total elongation of the 2-inch length. Errors

due to this cause may amount to 6 per cent. of the values given; thus, where an elongation is given as 66 per cent. the true value may be as low as 64 per cent. or as high as 68 per cent. Thus the values obtained in this way are only approximate.

A very slight acquaintance with the tensile properties at

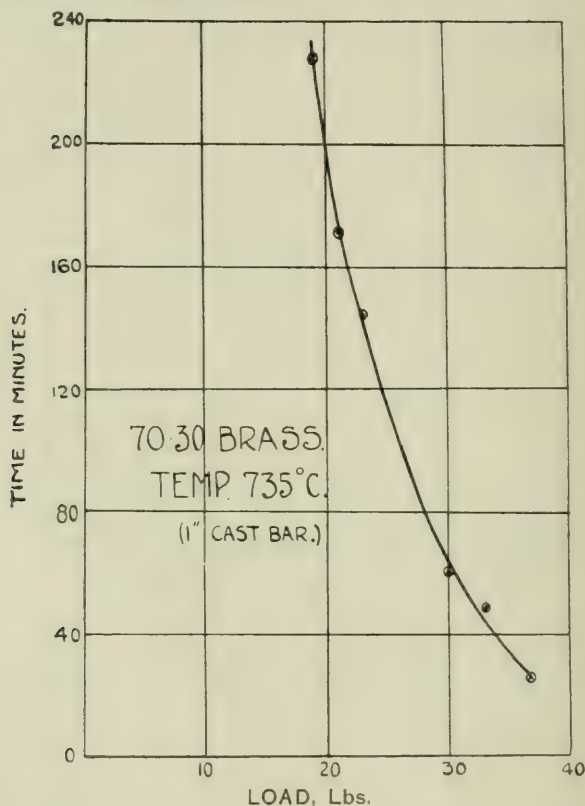


FIG. 5.

high temperatures was sufficient to indicate the importance of the time under load. Two typical curves are given to illustrate the phenomenon. Fig. 4 is for a wire $\frac{1}{8}$ inch in diameter, and Fig. 5 for a 1-inch cast bar; in each case the alloy used was 70-30 brass. These cases have been selected as representing the extreme cases of a highly stressed thin specimen

and a thick cast bar. Similar phenomena were noticed with all the alloys used, and became increasingly important as the temperature was raised. Below about 400°C . the effect was only slight, even if it existed at all. Precautions were taken to remove any error due to this phenomenon, and it was not investigated in any detail at temperatures below 500°C .

The method adopted for avoiding these errors was to keep the total time for which the specimen was under test approximately constant. The test period selected was twenty minutes. In actual practice it was possible to keep within the limits of fifteen minutes and twenty-five minutes, except in the case of great loads at low temperatures; here, however, the factor was not important.

In order to keep within the limits a rough idea of the properties of each specimen was required, so that an approximately correct rate of loading could be adopted. For this purpose preliminary tests were made for each alloy, but these tests have been omitted from the tables and curves now presented. To save expense they were made on thin straight bars $\frac{1}{4}$ of an inch in diameter; although they were not turned down at the centre, they always broke within an inch of it owing to the distribution of temperature along the bar.

MATERIALS USED IN THE MAIN RESEARCH.

It was desired to obtain typical curves representing the relations of stress and strain to temperature for the following classes of materials:—

- (a) Ordinary pure metals of commerce.
 - (b) Alloys consisting of a single simple solid solution, with no critical points beneath the solidus.
 - (c) Alloys consisting of two solid solutions or other phases.
- This class is very large, and many types are possible in it.

In each case both cast and worked materials were studied. In class (a) copper and aluminium were the materials selected. In class (b) a copper-nickel alloy was chosen, the reason being that this series of alloys consists throughout of simple solid solution of nickel in copper, and no doubt can be entertained

as to their simple character. Further to represent this class two specimens of 70/30 brass have been used, though it is possible the constitution of this alloy may not be quite so simple.

In class (c) various types of brass have been selected.

Analyses and descriptions of all the materials used in the research are given in Table II.

DETAILS OF THE MAIN SERIES OF EXPERIMENTS.

The materials as received were cut up into 12-inch lengths, and screwed at each end for $\frac{3}{4}$ inch. The rolled $\frac{1}{2}$ -inch round bars were turned down to a $\frac{1}{4}$ inch diameter, parallel for $2\frac{1}{2}$ inches; the cast 1-inch bars were turned down to $\frac{1}{2}$ inch over $2\frac{1}{2}$ inches. They were then marked by one of the methods already described. The thermo-junctions were next wired on to points between the gauge marks, and the whole placed in the furnace, and left till equilibrium had been obtained. It was very desirable that this should be reached as quickly as possible, and that the time occupied in reaching it should be nearly the same for all the bars of each series, since in this way the effects of annealing could be to some extent eliminated. By never allowing the furnace to cool, and by bringing it to a temperature a little above that required before the introduction of the bar, it was found that the $\frac{1}{2}$ -inch bars could be brought to a practically constant temperature in about one hour for all but the highest temperatures. The total interval of time from the introduction of the bar to the instant of fracture was usually about $1\frac{1}{2}$ hours. For the larger bars this period was about two hours. The temperature readings were taken at the instant of fracture, and are accurate to $\pm 4^{\circ}$ C.

The rate of loading the bars was adjusted so that the total time under test should be approximately the same for all bars of the same series. It was, in consequence, rapid with large loads, and slow with small loads. In the case of the stronger bars, at temperatures below 350° C., it was not possible to load rapidly enough to obtain fracture in twenty minutes, and in some instances nearly double this period was required for

TABLE II.—Analyses of Materials.

	SERIES I.	SERIES II. and III.	SERIES IV.	SERIES V.	SERIES VI.	SERIES VII.	SERIES VIII.	SERIES IX.	SERIES X.
	Copper.	Aluminium.	Copper-Nickel.	Brass A.	Brass B.	Muntz Metal A.	Muntz Metal B.	Brass C.	Complex Brass.
Copper . . .	Per Cent. 99.84 *	Per Cent. Trace	Per Cent. 79.99	Per Cent. 69.88	Per Cent. 69.4	Per Cent. 60.52	Per Cent. 59.52	Per Cent. 56.75	Per Cent. 55.1
Aluminium . . .	...	99.56 *	...	...	...	...	...	...	0.07
Nickel . . .	...	...	19.60	0.05	...	...	0.39	...	0.28
Zinc . . .	...	...	...	29.49	30.44	38.80	39.43	43.20	41.89
Tin . . .	...	...	...	...	...	...	...	...	0.77
Lead . . .	...	...	...	0.64	0.005	0.40	0.74	Trace	0.52
Iron . . .	Trace	0.22	0.41 +	...	0.15	...	...	...	0.84
Arsenic . . .	0.05	...	...	...	...	...	...	...	...
Sulphur . . .	0.005	...	...	...	...	...	...	...	...
Silicon . . .	...	0.22	...	...	...	...	...	...	...
Manganese . . .	0.08 (Oxygen)	...	...	...	...	...	...	...	0.36
Physical condition . . .	Rolled	Rolled	Rolled	Cast	Wire-drawn	Rolled	Rolled	Cast	Extruded
Constitution . . .	Pure metal	Pure metal	Single solid solution (a)	Single solid solution (a)	Single solid solution (a)	Two solid solutions (a + β)			

* By difference.

† Iron and manganese.

a single test. No appreciable error is thereby introduced, since at these low temperatures the time effect is small.

EXPERIMENTAL RESULTS.

These will now be dealt with separately for each series, beginning with the simplest cases of the pure metals, and leading up to the more complex cases of the two-phase systems. The whole of the results will then be summarised and discussed, and some general suggestions and conclusions proposed.

SERIES I.—*Copper.*

The stress-temperature results are given in Table III., and the corresponding curve is shown in Fig. 6. Le Chatelier's

TABLE III.—Series I.—*Copper (Rolled).*

Temperature of Test, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
17	O.T.*	16.5	31.5
17	O.T.	17.5	32.0
17	1800	16.3	32.5
17	1843	16.7	32.0
252	1393	12.7	28.0
290	1505	13.7	9.3
330	1197	11.0	29.6
370	1153	10.5	29.0
420	1043	9.5	28.0
480	823	7.5	27.5
540	570	5.1	27.0
620	287	2.6	27.0
675	169	1.3	28.4
736	141	1.2	36.0
740	141	1.2	78.0
775	111	1.0	66.0
840	105	0.96	61.0
920	60	0.50	69.0
960	36	0.30	50.0
1010	21	0.16	38.0

results are also given in Fig. 6; so far as they go, the two sets agree remarkably well. Unfortunately both Unwin and Le Chatelier stopped their work on copper before the most

* The letters "O.T." in the tables mean that the corresponding tests were carried out in the ordinary testing machine.

interesting range of temperature was reached. It will be noticed that at 650°C . the stress curve undergoes an abrupt change of direction. The upper part of the curve, which extends from the melting point (1065°C . oxidising atmosphere) to 650°C ., is a straight line. From 650° to the

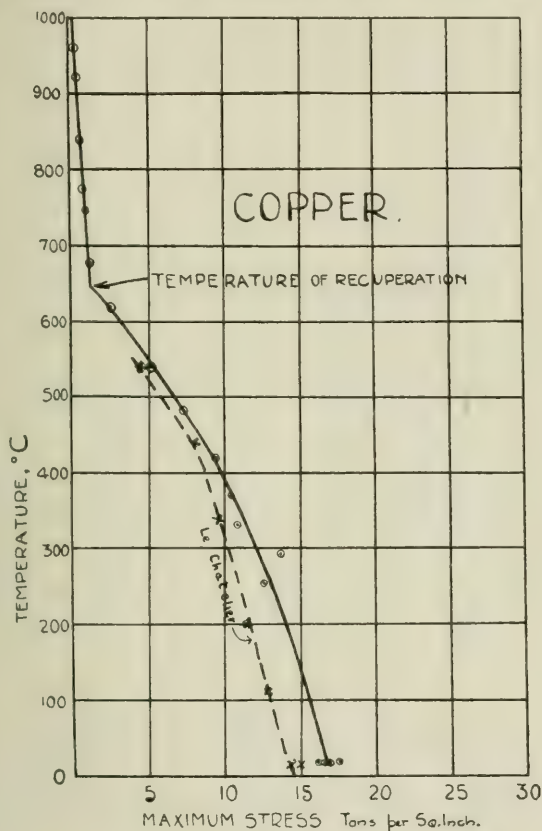


FIG. 6.

ordinary temperature the curve is convex upwards. Theoretically these two portions of the curve must merge gradually into one another so as to mask the exact transition point from one to the other, and whenever a considerable number of observations have been made in similar ranges the experiments have confirmed the theory. An exact transition point

can be obtained by extrapolation of the two parts of the curve, so that they meet. This transition point is called briefly by the author the *temperature of recuperation*, but the full title should be the *limiting temperature of complete recuperation*. The

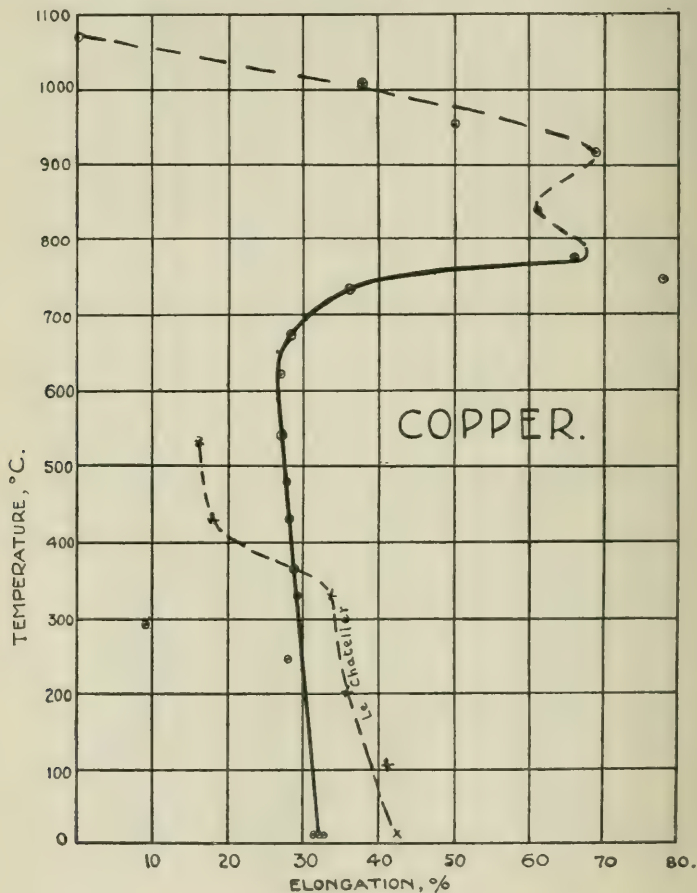


FIG. 7.

reason for adopting these terms will be stated later when the whole of the experimental results are being reviewed. Every tensile curve studied may be considered to exhibit a definite temperature of recuperation which can be deduced from the experimental curve by extrapolation; in most cases

the curves have been drawn so as to indicate these temperatures.

The strain-temperature, or elongation-temperature, curve is shown in Fig. 7. Contrary to what might have been expected, the elongation falls off slightly as the temperature is raised till 650°C. is reached. The elongation then increases at first slowly and then very rapidly; at about 920°C. it falls rapidly, the fall being due probably to almost complete loss of cohesion, and reaches zero at the melting point. It is uncertain whether or not a re-entrant angle really occurs in the curve at a temperature of 840° , since the single result shown in that range is not sufficient to establish it. For this reason the curve in the region of this temperature has been dotted in to indicate that it has not been satisfactorily determined. The important fact shown by the curve as a whole is that a decided change in direction occurs at 650°C. , and that at temperatures over 700° and below 900° the metal exhibits ductility of quite a different order from the rest of the temperature range.

Attention may be called to a single result obtained at a temperature of 295° , for which the author is unable to account; also to another at 740° , which appears to lie well off the curve. The differences between these two results and the values that might be expected for them from the general form of the curves are far beyond the possible errors of experiment.

SERIES II.—*Aluminium (Rolled).*

The stress-temperature curve (Fig. 8 and Table IV.) is of precisely similar form to that obtained for copper. The temperature of recuperation is 395°C. The strain-temperature curve (Fig. 9) is rather different, in that the elongation increases slowly up to about 390° , *i.e.* a little below the temperature of recuperation, and then undergoes a rapid and large increase. Above 400° the increase becomes slower till a temperature of rather over 600° is reached, when a rapid fall takes place, due probably to loss of cohesion.

Points to be noticed especially in the curves for copper and aluminium are:—

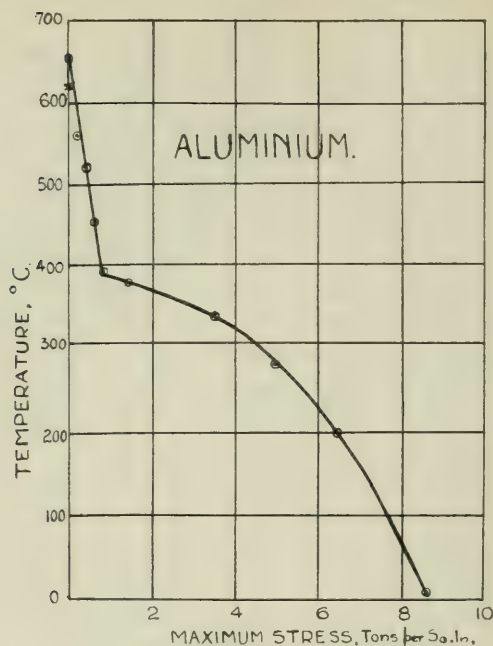


FIG. 8.

TABLE IV.—Series II.—*Aluminium (Rolled).*

Temperature of Tests, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.	Contraction of Area, per Cent.
	Lbs.	Tons per Square Inch.		
20	946	8.6	11.0	75
20	940	8.6	12.0	75
200	701	6.3	15.0	78
275	545	4.96	17.2	79
330	371	3.4	20.3	88
375	190	1.7	25.0	88
396	105	0.96	56.0	90
450	76	0.68	65.0	96
520	45	0.40	68.5	} Finest possible point
565	27	0.24	70.3	
610	33	0.30	75.0	
625	21	0.19	39.0	

(1) The well-marked change in direction of the stress-temperature curves at 650° and 395° .

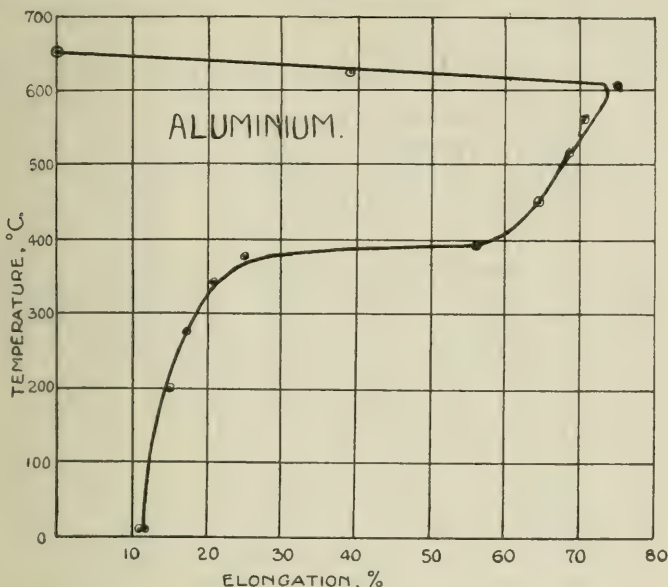


FIG. 9.

(2) The well-marked change of direction in the strain-temperature curves at approximately the same, but rather lower, temperatures.

SERIES IV.—*Copper-Nickel Alloy.*

This alloy consists of a single solid solution. The stress-temperature curve is given in Fig. 10, and is plotted from the results given in Table IV. It is of the same form as those of copper and aluminium, and the temperature of recuperation is about 710° . The strain-temperature curve (Fig. 11) differs from those of the pure metals. The elongation falls off till a temperature of about 650° is reached, and then increases somewhat rapidly, reaching a maximum at about 700° C. It then falls off again up to 750° C., and lastly rises till a temperature of at least 1010° is reached. The melting point of this alloy was 1190° C., but it was not

found practicable to carry out experiments at temperatures much above 1000° , hence no evidence of a final turn back of the curve in the neighbourhood of the melting point could be obtained.

This curve should be compared with that given for 70/30

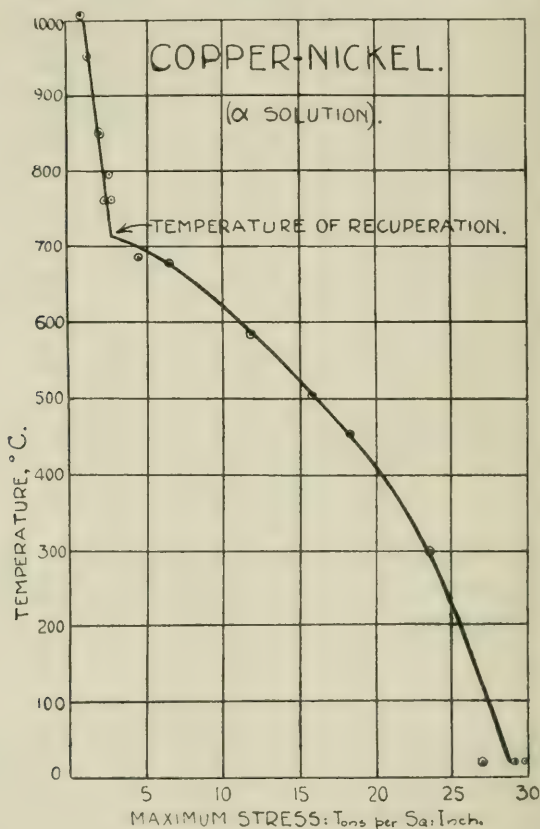


FIG. 10.

brass (α solid solution) by O. F. Hudson and the author in volume iv. of this *Journal*, and now reprinted in Fig. 24. The form of the two curves will be seen to be nearly similar, and the peaks in the curves, which occur in each case at about the temperature of recuperation, are particularly to be noticed.

TABLE V.—Series IV.—Copper-Nickel Alloy.

Temperature of Test, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
17	O.T.	27.1	26.0
17	O.T.	29.8	28.2
17	...	29.2	28.0
300	2596	23.7	23.5
456	2016	18.4	20.3
505	1736	15.8	20.0
580	1323	12.0	15.5
675	735	6.7	20.2
685	498	4.5	31.2
760	321	2.9	23.4
760	273	2.5	22.0
795	287	2.6	26.5
850	241	2.0	27.2
950	129	1.1	31.2
1010	117	1.0	37.0

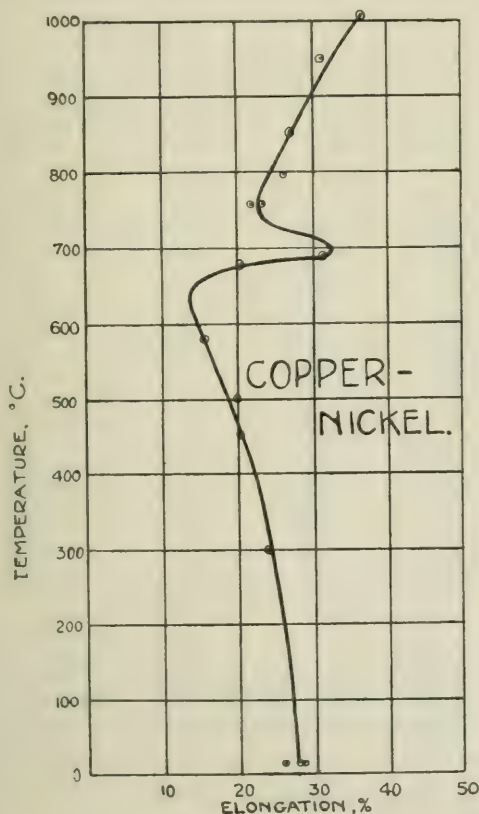


FIG. 11.

The microstructure of this alloy, and the effect on it of annealing, are shown in Plate XV. Figs. 2 to 6.

SERIES V.—*Brass "A."*

This alloy, like the last, consists of a single solid solution, the *a* solution of the copper-zinc series. The results obtained with it are given in Table VI., and plotted in Figs. 12 and 13. The stress-temperature results appear to fall on two curves, which meet at about 440° , and are both approximately straight lines. Fig. 12 should be compared with the stress-temperature curve for 70 30 brass wire given in vol. iv. of this *Journal* by O. F. Hudson and the author.

TABLE VI.—Series V.—*Cast Brass.*

Temperature of Test, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
As cast	O. T.	12.1	39
As cast	O. T.	12.2	37
290	2541	5.7	15
325	2229	5.0	11
345	2152	4.9	9
400	1281	2.9	3
432	1101	2.5	2.0
465	1279	2.9	3.2
496	1057	2.4	4.4
530	917	2.0	3.5
560	959	2.1	5.0
600	833	1.9	9.3
620	819	1.8	8.0
625	553	1.2	20.0
635	685	1.5	18.5
650	589	1.3	18.0
680	463	1.0	17.2
710	443	1.0	15.6
745	301	0.67	12.5
785	189	0.43	11.0

The strain-temperature curve of this alloy is remarkable. The elongation falls quite rapidly till a temperature of just over 400° C. is reached, and it may be mentioned here that this phenomenon occurs in all alloys which contain the *a* solution of the copper-zinc series in any considerable

quantity, as well as in some alloys that only contain a trace of it. In the case of the brass now being considered, and of the wire used in the experiments already referred to by O. F. Hudson and the author, the minimum values for elongation were obtained in each case at a temperature of

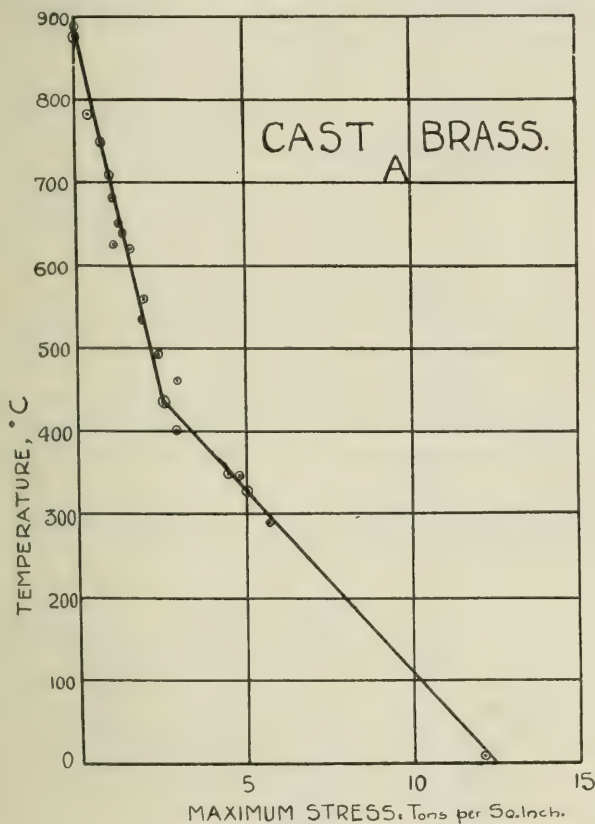


FIG. 12.

about 410°, and are practically identical numerically, namely, 1.5 and 2 per cent.

Above 430° C. recovery sets in with both these alloys. In the case of the wire this recovery is very rapid, and a new maximum of value is obtained at 450°. With the cast bar the recovery is very much slower, and the new maximum is

only reached at a temperature of 625°C . In both cases the actual value is approximately the same, namely, 18.5 and 17.5. After the maximum is reached, the elongation falls off, in the case of brass "A," quite steadily up to the melting point. In the case of the wire the curve resembles that of the copper-nickel alloy, and the fall only takes place in the neighbourhood of the melting point.

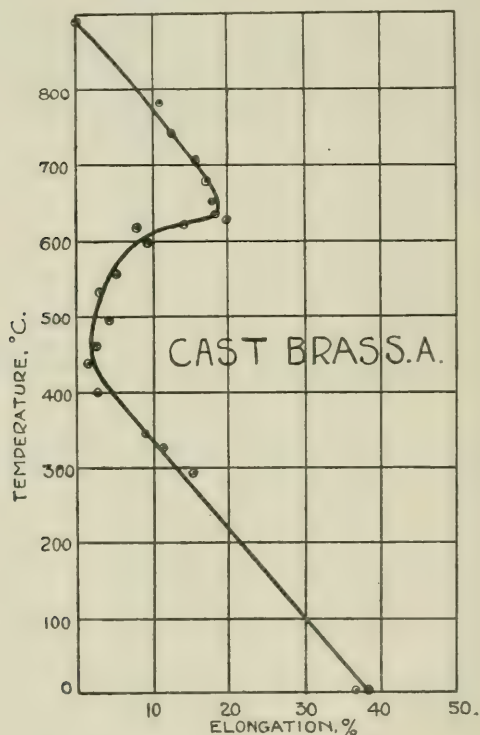


FIG. 13.

It will be seen that though there are several points of resemblance in the general form of the curves, there are also points of difference. Perhaps a close resemblance could hardly have been expected between material so different physically as a hard-drawn wire one-eighth of an inch in diameter and a 1-inch cast bar. Chemically, the latter differs from the former in containing an additional 0.5 per

cent. of lead, and a considerable part of the difference between them may probably be put down to this fact.

TWO-PHASE SYSTEMS.

The mechanical properties of a number of two-phase systems may now be considered. It must be said at once that the complete interpretation of the curves obtained experimentally for these systems is by no means easy, and the remarks made by the author in dealing with each of these systems are intended to be suggestive rather than authoritative. Much further study is required in this branch of the subject.

SERIES VI.—*Muntz Metal "A."*

This alloy is the first of the two-phase systems. Its microstructure is illustrated in Plate XV. Fig. 1. It consists of the α and β solid solutions, and it should be noticed that the α constituent (shown light in the photograph) forms the matrix in which the β solution is imbedded. From this it would be expected that the characteristics of the α solution would predominate in the alloy, especially at low temperatures.

TABLE VII.—*Brass Wire.**

Mark.	Tested at Degrees C.	Maximum Stress, Tons per Sq. In.	Elongation, per Cent. on 2 Ins.	Contraction of Area per Cent.
W29	310	18.1	2.5	11
W31	310	19.0	2.0	10
W30	313	16.3	2.0	2
W32	415	10.8	1.5	10
W33	415	10.3	1.5	9
W38	440	5.1	6.0	15
W39	453	5.1	17.5	30
W34	465	4.8	16.5	29
W35	472	4.4	16.25	29
W36	472	4.6	16.25	29
W40	500	3.4	13.7	28
W41	500	3.5	13.0	22
W42	590	1.3	16.0	22
W43	590	1.2	14.0	18

* "The Heat-treatment of Brass," Bengough and Hudson, *Journal of the Institute of Metals*, No. 2, 1910, vol. iv.

At high temperatures, at which the β constituent increases in quantity at the expense of the α , it would be expected that the characteristics of the α solution would be much modified.*

The experimental results are given in Table VII., and Figs. 14 and 15. The stress curve shows two branches; one is slightly concave upwards. The first branch extends

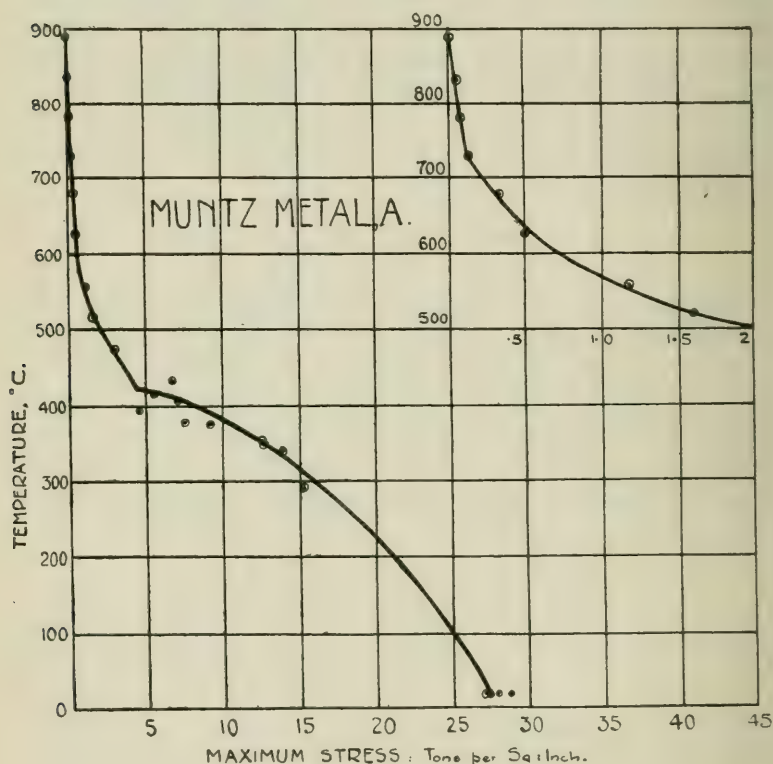


FIG. 14.

from 0° to 430° , the second from 430° to the melting point 890° . The strain curve is rather more complex, and will now be considered in detail.

* It must be clearly borne in mind that the mechanical properties of both the α and β solutions alter with their composition. In all Muntz metals the α solution is always saturated, and so will have definite mechanical properties which only vary with the temperature.

Between 0° and the 300° the elongation falls off rapidly, and reaches a minimum value at about 350° . It then increases again rather rapidly up to a temperature of 395° . The general shape of the curve in this region resembles that of the α solid solution (Figs. 13 and 22). It differs in that the minimum value is 7.6 per cent. instead of 1.5 per cent., and that recovery sets in at a lower temperature. Both these

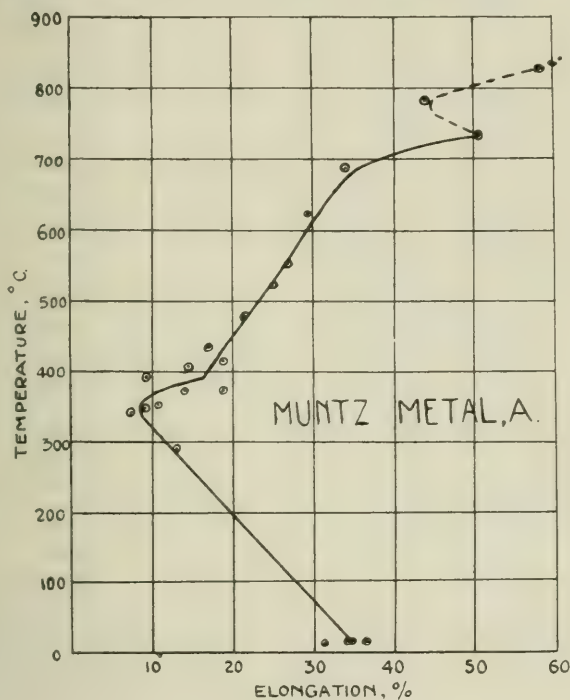


FIG. 15.

deviations would be expected as results of the presence of the β phase, which will be shown later to be a phase of low strength but considerable ductility at moderate temperatures whenever its strength can be improved.

The presence of β , then, when associated with α , masks the entire loss of ductility by the α solid solution, and enables recovery to begin at a lower temperature, namely, 350° instead of 410° . The slope of the curve between 340° and 390° was

very difficult to determine, and has been examined experimentally with great care. At first the recovery seems to be due mainly to the increasing importance of β . Above about 400° , however, it will be assisted by the recovery of ductility of the α also.

These two factors help one another throughout the temperature ranges 400° to 730° , and the increase in ductility is therefore quite rapid. This branch of the curve ends at a temperature of 730° C., and 51 per cent. elongation. The stress curve undergoes a slight change of direction at 720° , and with this is associated the sudden increase of elongation at about the same temperature.

Several similar cases of rapid increase in elongation at a critical point in the stress curve may be seen in the curves already described; the phenomenon is a usual one, though perhaps not quite universal.

At 730° the constitution of this alloy undergoes an entire change. Quenched specimens show that above this temperature it consists of pure β . In Shepherd's diagram the temperature of this change for an alloy of similar composition is given as 745° , but there is reason to suppose that the precise slope of the curve between the β and $\alpha + \beta$ areas in this neighbourhood has not been determined with an accuracy greater than 10° or 15° C. Above 730° the curves represent the properties of the partially saturated β solution.

A question arises as to the effect on the mechanical properties of the inversion at 475° discovered by Carpenter and Edwards. The author now believes that, though this change is a very real one, it does not appreciably influence the shape of the curves here published. The reason for this is that the change is too slow to make any serious headway in the short time for which the bars were heated in the furnace.*

SERIES VII.—*Muntz Metal "B."*

This alloy, like the last, consists of two solutions. It contains just 1 per cent. more zinc. A microphotograph of the

* [The paper read by Professor Carpenter at the meeting at which the present paper was read has necessitated a modification of this view. See Discussion.—Ed.]

alloy is shown in Plate XV. Fig. 2. It will be seen that the structure differs from that of Muntz metal "A," in the important fact that the β now forms the matrix, in which the α is distributed, instead of the reverse arrangement. It is to be expected, therefore, that the characteristics of the α curves would be largely or entirely masked, since the stress and strain must now fall principally on the matrix solution.

The curves obtained experimentally from this alloy fulfil

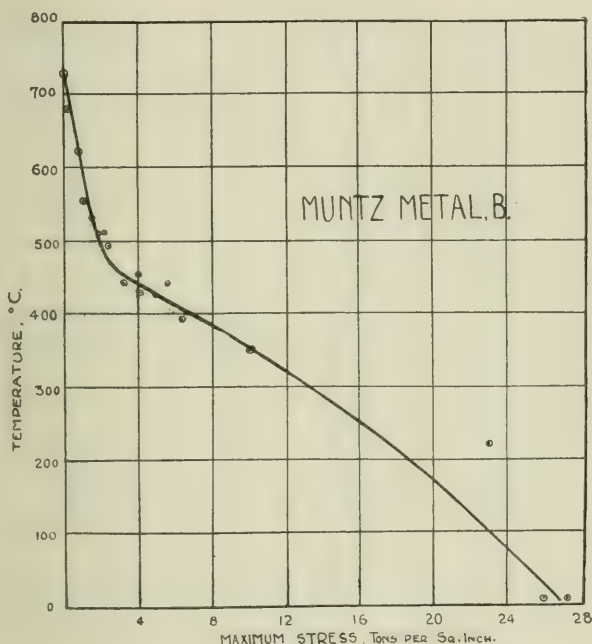


FIG. 16.

these predictions. They are shown in Figs. 16 and 17, and are plotted from the values given in Table VIII. Instead of a rapid falling off in the elongation so characteristic of the α solution, the curve is nearly vertical up to a temperature of 400°. At this temperature the α solution has lost practically all its ductility, but the β has acquired a moderate amount. It was found in the experiments that this alloy gave very variable results in the range of temperature between 400°

and 500° , and it has been found impossible to plot a characteristic curve in this neighbourhood. The cause of this is probably to be found in the fact that the α and β solutions are present in this range of temperature in very nearly equal amounts, and are also of approximately equal strength, though at the lower temperatures the β is slightly stronger. Consequently the strain may fall on either of them, according to

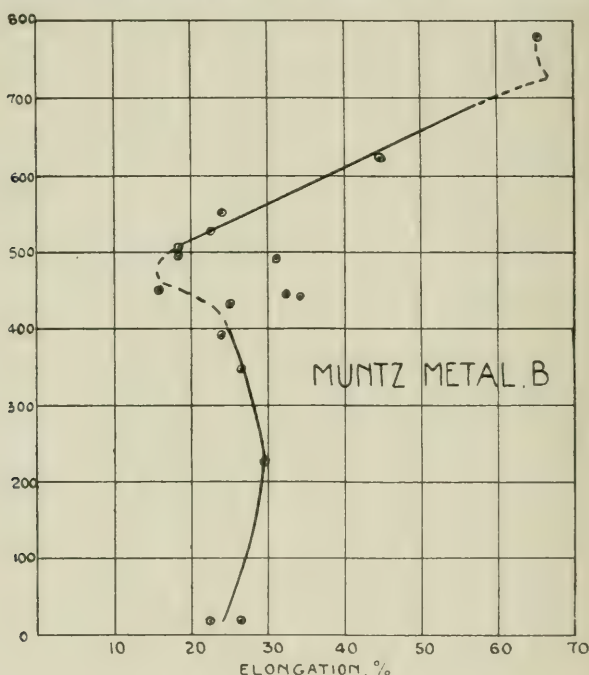


FIG. 17.

the detail of their relative arrangement in the actual bar examined. If the strain fall mainly on the α the ductility will be very small; if it fall on the β it may be fairly high. Hence in this region no two bars behave exactly alike. At temperatures above 500° the β solution increases in amount at the expense of the α , and consequently impresses upon the bar its properties of great ductility and low strength, with the result that the curve passes off rapidly to the right.

It is interesting to compare the curves for the two samples

of Muntz metal. It will be seen that they are of quite different types at all temperatures below 700° —in fact, they are as different as if they represented the properties of two entirely different alloys. The sensitiveness of these alloys to very small differences of composition in this range must be a

TABLE VIII.—Series VII.—*Muntz Metal "A."*

Temperature of Test, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
17	O.T.	27.1	32.2
17	O.T.	28.9	34.0
17	...	27.7	36.5
17	...	28.1	34.6
292	1666	15.1	13.0
340	1523	13.9	7.6
349	1401	12.7	9.4
356	1397	12.7	10.9
375	1005	9.1	14.1
376	805	7.3	19.0
396	511	4.6	9.3
405	777	7.0	14.1
416	609	5.5	18.7
432	735	6.7	17.1
475	329	3.0	21.8
520	175	1.6	25.0
560	133	1.2	27.0
625	59	0.5	29.6
685	38	0.34	34.5
730	16	0.14	51.0
780	11	0.09	44.0
830	7	0.57	58.4

fact of great industrial interest and importance. The difference in inclination between the two curves at temperatures above 500° must be due to the fact that a slightly increased proportion of the β phase confers on the alloy greater ductility at high temperature.

SERIES VIII.—*Cast Brass "C."*

It was thought that it would be interesting to cast a few bars of such composition that they would consist entirely of pure β .

Unfortunately the resources of the author's laboratory did not

at the time allow of the metal being melted in sufficient quantities to make the bars required. The matter has since been remedied, but too late for the bars to be cast and tested in time for the present paper. Consequently the bars had to be cast outside the University, and were found to be rather higher in copper than corresponds to pure β —that is, they contained 56.7 per cent. of copper instead of 54. Nevertheless, the tests of these bars are interesting. They consist very largely of β crystals, with quite small α crystals scattered about amongst the matrix (Plate XVI. Fig. 11); it is evident that the mechanical properties of the bar will represent very closely the properties of the nearly pure β solution. The experimental results are given in Table IX., and are plotted in Figs. 18 and 19. It will be seen that at the ordinary temperature the β

TABLE IX.—Series VIII.—*Muntz Metal "B."*

Temperature of Tests, Degrees Centigrade.	Elongation, per Cent. on 2 Inches.	Maximum Stress.	
		Lbs.	Tons per Square Inch.
17	26.7	O.T.	27.2
17	22.7	O.T.	25.8
225	29.6	2569	23.2
350	26.5	1120	10.0
395	24.2	742	6.5
428	25.0	502	4.6
430	34.3	651	5.9
440	32.0	364	3.2
450	16.1	441	4.0
490	31.2	231	2.2
496	18.5	189	1.7
510	18.7	225	2.0
510	...	217	1.9
530	22.5	189	1.7
550	24.0	119	1.08
625	44.5	<105	<0.96
675	51.5	24	0.16
780	65.6	11	0.08

solution has considerable strength; it is, in fact, at least equal in this respect to the cast α solution (see p. 164). On the other hand, it has practically no ductility. The elongation, however, increases steadily with the rise in temperature up to 610°, when it reaches a value of over 30 per cent. It seems almost certain that the slight check in the rise of the

curve at 400° is due to the presence of the trace of α which happened to be arranged in the particular bar tested at this temperature, so that it could exert its influence. At 600° C. the curve turns back, showing a loss of ductility. At this temperature, however, the alloy consists of pure β , and this turn back in the curve must mean that the strength of the

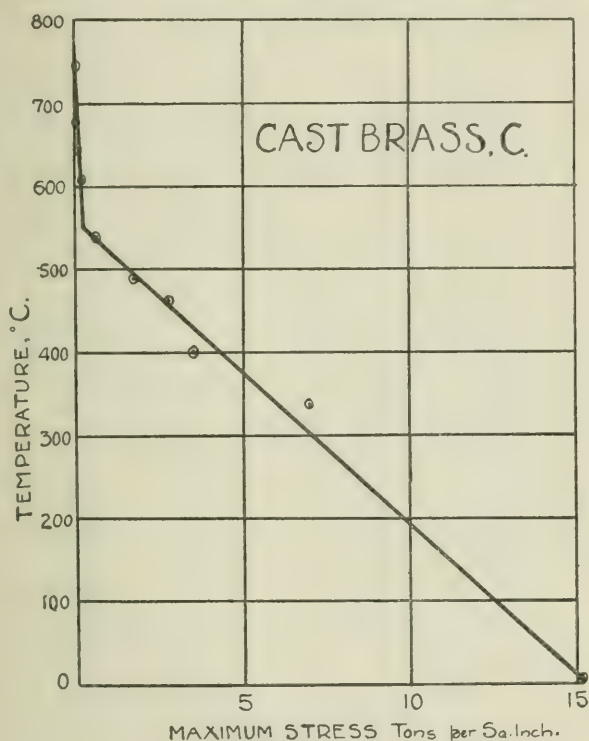


FIG. 18.

β phase, of the composition of this alloy, has now become so low that its great ductility is not available; in fact, it rather resembles lead in its mechanical properties.

Plate XVII. Fig. 14 shows the microstructure of the bar broken at 700° , in the neighbourhood of the fracture. After fracture the bar was withdrawn from the furnace and cooled naturally in air. The large crystals are β , and round the

edges of them a thin film of α has crystallised out. At the temperature of fracture no α was present, as was shown by quenching small specimens. With regard to this microphotograph, it may be mentioned in passing that the β solution, rather high in zinc and approximately pure, is without exception the most difficult alloy known to the author to obtain

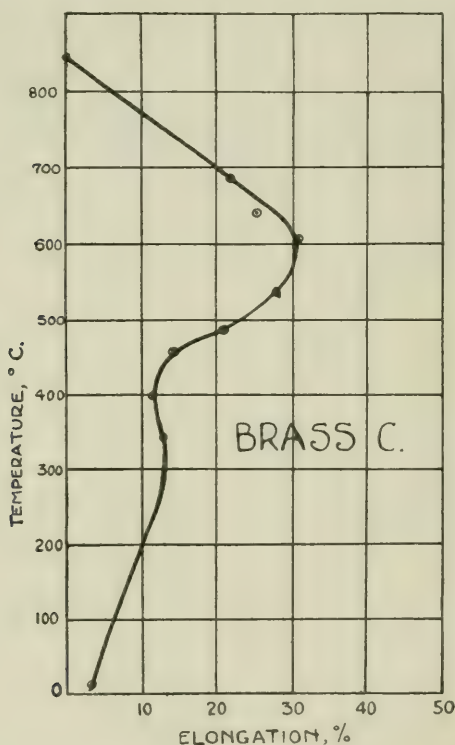


FIG. 19.

free from scratches for photography; hence the appearance of the microphotograph in question.

Plate XVII. Fig. 12 is a photograph of another bar of the same alloy, as cast; the only mechanical work that had been put on the bar was due to screwing the ends. The network seen in the photograph only became apparent after etching. The author believes it to be a very fine cubical cleavage which

had been developed in the brittle material by the mechanical stress caused by the screwing. The cleavage has been opened out and made visible by the etching agent gradually finding its way along cleavage planes.

At high temperatures the ductility of bars of this alloy cannot be satisfactorily measured, owing to the fact that numerous wide cracks open up in the bar at considerable distances from the point of fracture. This phenomenon was also observed at all temperatures above 400° , and at 700° rendered elongation measurements meaningless. These bars also showed a tendency to break outside the gauge marks and at the shoulder, and many tests were spoilt in this way. Only the results of satisfactory tests have been recorded in the tables and curves.

TABLE X.—Series IX.—Brass "C."

Temperature of Tests, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
18	O.T.	15.1	3.1
330	2998	6.8	12.5
400	1512	3.4	11.0
460	1202	2.6	14.0
480	847	1.9	21.0
530	245	0.56	28.1
610	98	0.20	31.0
640	35	0.07	25.0
685	33	0.06	22.0
740	30	0.06	...

SERIES X.—Complex Brass.

The elongation curve of this alloy is very remarkable, and is shown in Fig. 21, which is drawn from the results in Table XI. This alloy has two small thermal critical points in the solid, at 720° C. and 560° . There does not appear to be any abrupt change in mechanical properties corresponding with the latter. The analysis of this alloy shows it to be a very complex material, and the object of introducing the subsidiary constituents appears to be to improve and strengthen the mechanical properties of the β phase.

TABLE XI.—Series X.—*Complex Brass.*

Temperature of Test, Degrees Centigrade.	Maximum Stress.		Elongation, per Cent. on 2 Inches.
	Lbs.	Tons per Square Inch.	
17	O.T.	40.3	21.0
17	...	40.0	22.0
250	...	21.2	40.2
300	1727	16.0	46.8
350	1267	11.7	60.0
420	505	4.6	59.3
432	613	5.5	59.3
440	496	4.5	51.5
460	368	3.3	62.5
475	382	3.4	51.5
510	307	2.7	48.5
515	294	2.7	68.2
524	280	2.4	97.0
525	140	1.2	105.0
530	273	2.4	100.0
535	160	1.5	106.2
535	183	1.5	107.5
615	140	1.2	140.0
700	<105	>0.96	162.5
750	10	...	156.3
790	7	...	128.0

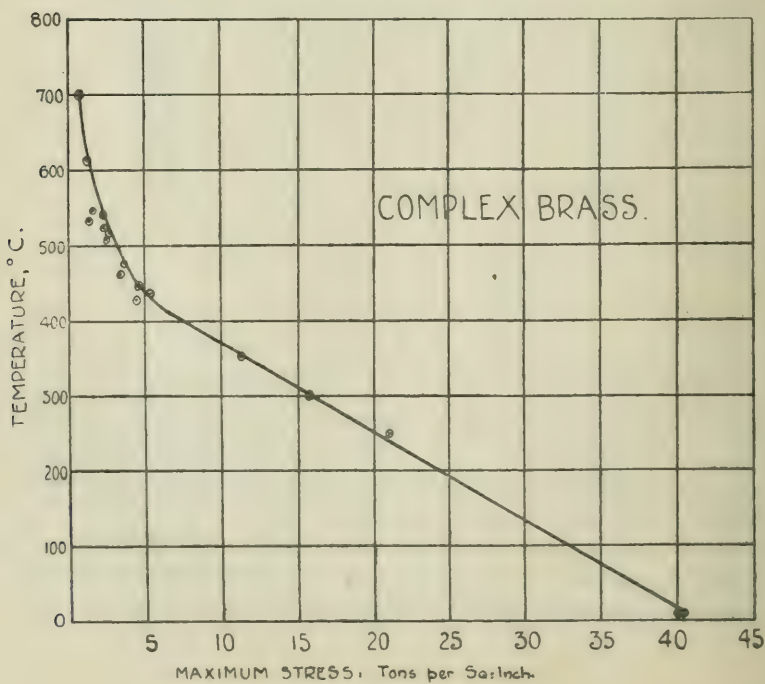


FIG. 20.

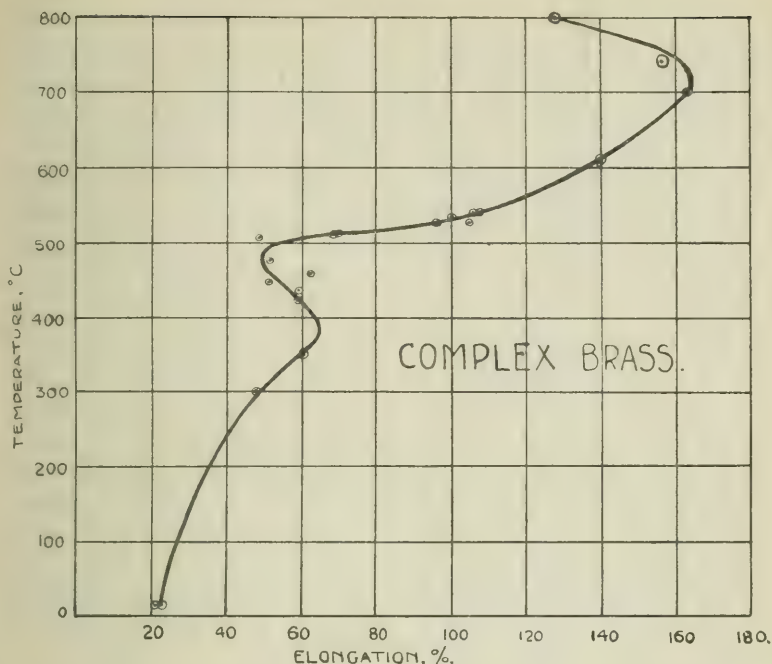


FIG. 21.

GENERAL DISCUSSION OF EXPERIMENTAL RESULTS.

It will be noticed that the stress and strain curves of the pure metals show changes of direction which are most abrupt at a temperature of 650°C . in the case of copper, and at 395°C . in the case of aluminium. These points may be referred to as "mechanical critical points," to distinguish them from the well-known thermal critical points of metals and alloys. Now the pure metals copper and aluminium exhibit no thermal critical points at temperatures corresponding to the mechanical critical points, and we must come to the conclusion that there is no necessary relation between the two sets of phenomena. Further, the only changes that take place in the microstructure of these pure metals as the temperature rises are the increasing crystal size, and the removal of the amorphous material formed in and around the crystals as the result of cold work, con-

traction strains, &c., on the metal. The conclusion, therefore, appears to be inevitable that there are certain powerful factors, hitherto unrecognised, which profoundly affect the mechanical properties of pure metals and alloys, and which have no relation that has yet been traced to their phase relationships.

An examination of the whole series of tensile curves now published will show an interesting difference between those representing materials rolled or worked at a comparatively low temperature, such as aluminium, copper, 70/30 brass, copper-nickel, and those representing cast materials, or materials only worked at high temperatures, such as "extruded metal." In Fig. 22 the curve XYZ is a typical stress-curve of the former class of material; the curve XYZ of the latter type. The curves indicate that at any temperature below Y rolled metal is stronger than similar cast material, but that at temperatures above Y both materials have identical properties. This temperature Y at which the curve XY meets, the curves YV and YZ has been determined both for cast and rolled metal in the case of aluminium, and has been found to be 395°C . *for both classes of material.* A discussion of the position of Y horizontally will be taken up later.

The horizontal distance, BC, shows the difference in strength, at a temperature of 250° , between the cast and rolled materials. As the temperature is raised this difference in strength becomes smaller and smaller, till it vanishes at Y.

It now remains to discuss the physical meaning of this remarkable series of phenomena, and to supply a rational explanation of it.

Before doing so, the physical properties of metals and alloys above the temperature Y and below the melting point must be described. In this range their behaviour resembles that of a viscous fluid; their strength is very small, they exhibit great ductility and plasticity, and the influence of time on the tensile strength becomes important. Moreover, in nearly all cases, they give out a "cry" like that of tin when stressed by loads much less than that required for fracture. This "cry" is particularly noticeable in the case of the brass alloys and copper. The "cry" of tin is usually explained as due to the rubbing of the crystal surfaces against one another,

or more probably to the tearing of one crystal surface from another.

This remark naturally leads to the consideration of the question why other metals do not "cry" when stressed at ordinary temperatures. The answer may reasonably be given that tin is above the temperature Y, its "temperature of recuperation," at the ordinary temperature, whereas most other

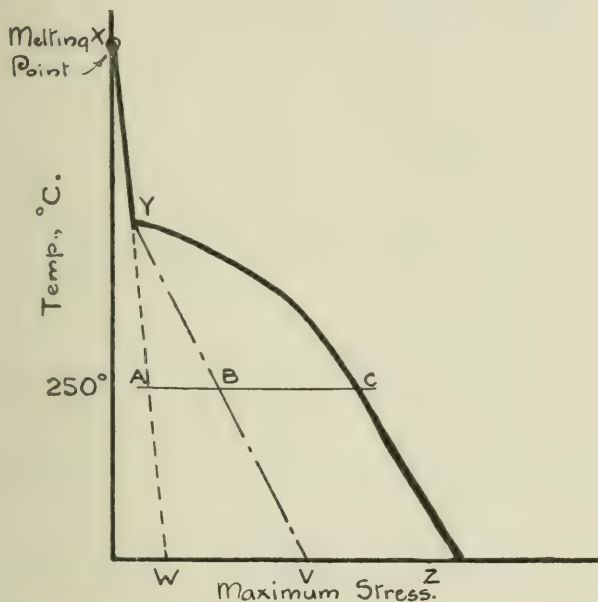


FIG. 22.

metals and alloys are not, and that it is only at temperatures above Y that the crystals can come in actual contact with one another.

It has always appeared a remarkable fact to the author that the fracture of metals and alloys tends to pass through the body of the metallic crystals rather than between the crystalline junctions, especially in the case of pure metals and solid solutions. (Cases of fracture passing through weak inter-crystalline eutectics do not affect the present argument.) It would seem that at the ordinary temperature the cohesion between the faces of separate crystals is greater than that

between different parts of the same crystal—a really remarkable phenomenon which has not perhaps received the attention it deserves.

Another fact of some significance in this connection is the peculiar action of etching agents upon pure metals and homogeneous solid solutions. The first action of a dilute

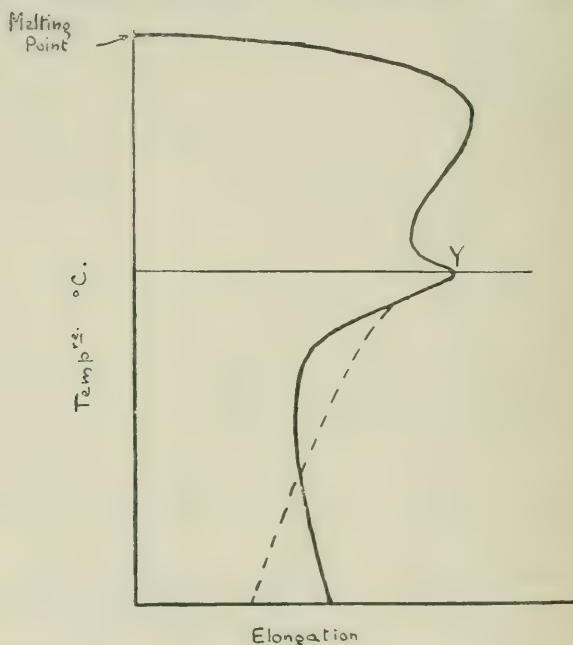


FIG. 23.

reagent is to eat into the crystalline boundaries and so bring out the polygonal structure characteristic of these substances.

The deduction may reasonably be drawn that the individual crystals in a pure metal are normally bound to one another by some substance stronger than the crystals themselves, but more easily attacked by etching agents. This substance must surely be no other than Beilby's amorphous material,* arranged in a thin, more or less continuous layer round the crystals. Its presence has hitherto only been clearly recognised in

* In general, this amorphous material exhibits greater strength but less ductility than the crystalline substance from which it is formed.

highly worked or strained metal; from the experiments now described it would seem to the author to exist in all metals and alloys below a certain temperature, characteristic of each material—the temperature of recuperation.

Its presence may be accounted for in the following ways. Firstly, it may result from the counter-attractions of the

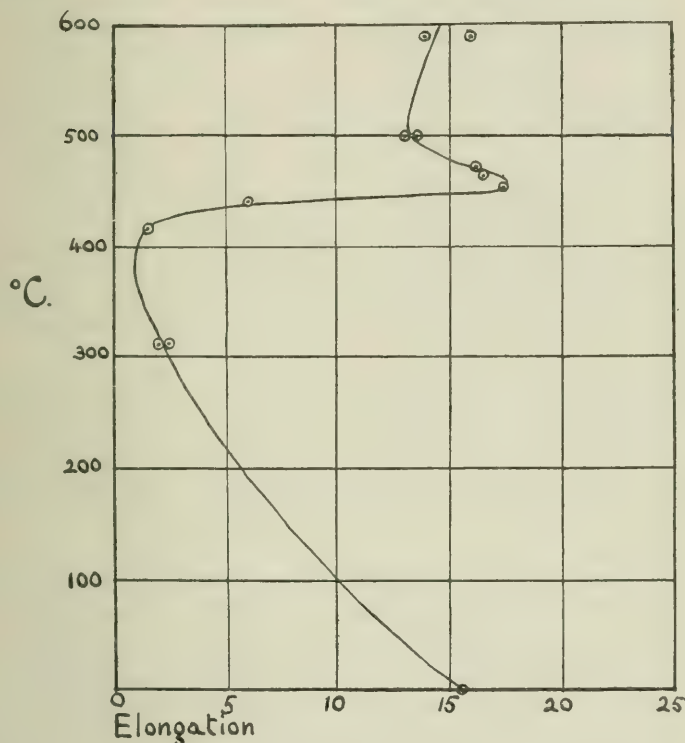


FIG. 24 (Bengough and Hudson).

crystals on either side of it, none of which is sufficiently strong to overcome the crystalline attraction of all the neighbouring crystals, and so to incorporate the last minute trace of still liquid material into its crystalline system. Secondly, it may result, or at any rate be increased in quantity, by the effect of contraction strains in the metal. That these may be very considerable is evidenced by the fact that they sometimes

give out audible sound waves during the process of relief. Thirdly, it may result from an increase in viscosity of the still molten metal, which in turn may result from the concentration in the last liquid portions of an impurity. Great viscosity is known to hinder crystallisation, and so to help in the formation of amorphous material.*

Now, at temperatures above Y, it may be supposed that the amorphous material which cements the crystalline faces together is no longer able to exist even momentarily. Hence fracture will take place between the crystalline junctions, and the fractured surface of specimens broken at high temperatures serves to support this view. Further, when slip takes place in the crystals themselves, the resulting mobile material instantly recrystallises, owing to the great activity of crystalline growth at these temperatures. Consequently "work" will no longer strengthen and harden the metal, and a precise definition of "hot-work" can be readily formulated. This definition is as follows.

Hot-work is work performed on a metal or alloy at such a temperature that the amorphous or mobile material formed at the expense of the crystals recrystallises instantaneously, leaving the material in a perfectly soft condition. The lowest temperature at which this is possible is called the temperature of recuperation.

Cold work will be work carried out partly or wholly below the temperature of recuperation, and will result in the formation of the amorphous material in considerable quantity.

The meaning of the term "the limiting temperature of complete recuperation" is now apparent. It means that, *under the conditions of the experiment*, the amorphous substance has no appreciable period of existence. It is also intended to cover the fact that the rapid falling off in tensile strength is abruptly checked.

It will be well to consider for a moment the phenomena which take place in a bar under test at temperatures above the temperature of recuperation. A load is applied; plastic deformation takes place; mobile molecules are formed along

* The influence of traces of impurity in destroying the ductility of masses may possibly be explained in this way, since amorphous metallic materials have little ductility.

the planes of slip; these molecules have an infinitely short period of existence and at once recrystallise, and this may happen before any further load is applied. If, however, the rate of loading is very rapid, it is just possible that complete

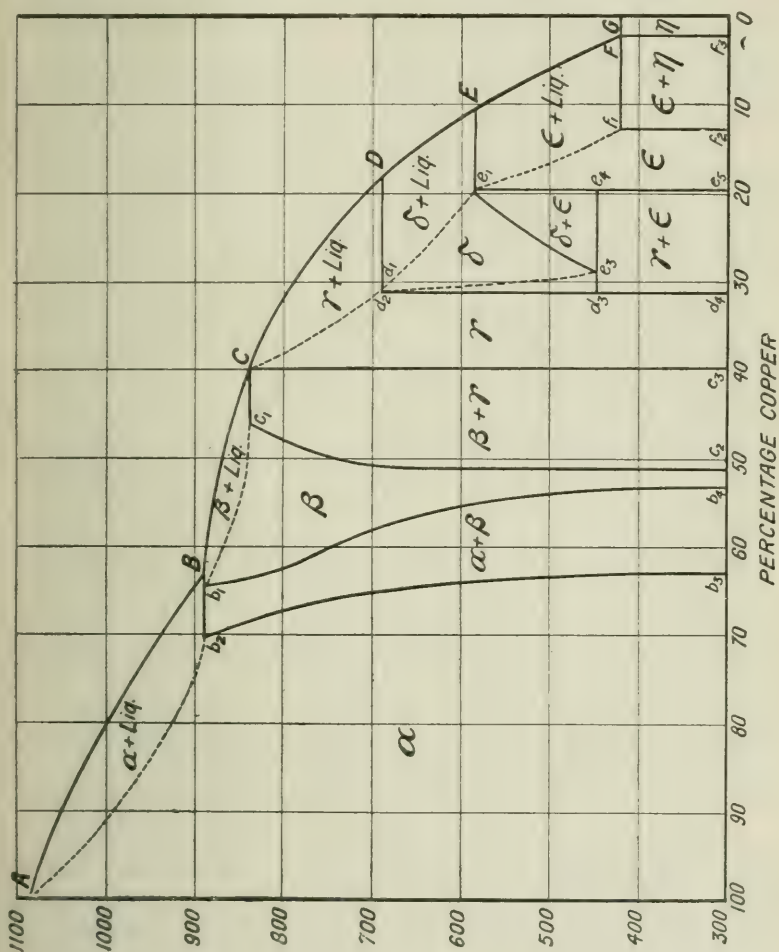


FIG. 25.

recrystallisation may not have had time to take place and a residue of amorphous material is left. Therefore, unless the rate of recrystallisation is rapid as compared with the rate of loading, the actual temperature of recuperation determined

experimentally will be dependent to some extent on the latter factor. Hence the use of the words "under the conditions of the experiment" in the last paragraph.

Turning now to Fig. 22, the difference in strength indicated by the line BC between a rolled and a cast material will be due to the amount of work put on it by forging, rolling, &c. If the curve XY be extrapolated down to the ordinary temperature, as shown in YW, we shall obtain the area YAWV. The curve YW obviously shows the properties which a metal would have at any temperature if it could be prepared and tested at that temperature in a perfectly crystalline state, without any amorphous material being formed in it. This is, of course, impossible, since the mere act of testing at any temperature below Y results in the formation of the hard amorphous substance. The curve XYW may therefore be regarded as representing the properties of an ideally soft metal, or of a metal whose temperature of recuperation is below the ordinary temperature. The line AB, then, represents the strengthening effect of the mechanical work necessarily put upon the metal by the act of testing, and also any small effect which results from contraction strains resulting from cooling.

If the foregoing views be accepted, it will be seen that the unstable, vitreous amorphous material of Beilby plays a far more fundamental part in determining the mechanical properties of metals or alloys than has hitherto been suspected. The industrial alloys of copper, and even copper itself, depend for their commercially useful properties entirely upon this material. Without it all metals would be weak, plastic, viscous bodies, rather resembling pitch, or perhaps tin.

An apparent discrepancy between Beilby's results and those of the author may now be referred to. In his May lecture* before this Institute, Beilby republished a number of his results which showed that the amorphous material in his copper wires recrystallised completely at 220°C . This might be supposed to correspond with the author's temperature of recuperation for copper, namely, 650°C . A careful consideration of the two sets of tests will show clearly, however, that there is no direct relation between them—salient points of

* *Journal of the Institute of Metals*, No. 2, 1911, vol. vi. pp. 5-43.

difference being that Beilby's wires were comparatively slightly stressed so as to give a 1 per cent. elongation, whereas the author's were stressed to fracture, and that in the author's experiments the amorphous material was being continually re-formed in quantity by the test itself.

Returning to the consideration of the experimental results now presented, and leaving on one side any further consideration of the theoretical suggestions outlined above, the author would direct attention to one or two matters that have not yet been considered in sufficient detail.

In the first place, it would appear from the curves that the elongation of an alloy is far more easily upset by variation in temperature, size of specimen, and possibly other factors, than is the maximum stress. The "mechanical critical points" in the elongation curves are decidedly more well-marked than in the stress curves, especially in the case of pure metals. The exact interpretation of some of the curves determined experimentally is difficult, especially in the case of two-phase systems. This arises from the fact that the properties of the α solution are very remarkable, and the elongation curve bends in a manner that is obviously dependent on a number of factors which are not yet clearly known, but some of which may be associated with slight differences of chemical composition and of size of bar. In the author's experiments the thick cast bars were tested at approximately the same rate as the smaller bars and wire. The resemblances and differences between cast bar A and the 70/30 brass wire have already been alluded to. If the respective times under test had been proportioned to the relative thicknesses, a closer resemblance might have been attained, and the shapes of the curves seem to suggest this.

The general type of elongation curve for pure metals is clear from Figs. 7 and 9. From these it may be seen that elongation may either increase or fall off as the temperature is raised, and it may be inferred that it may remain practically constant, up to the temperature of recuperation. At about this temperature it will undergo a large increase, and remain at a high value till the neighbourhood of the melting point is reached.

The general type of curve for a solid solution is not quite so

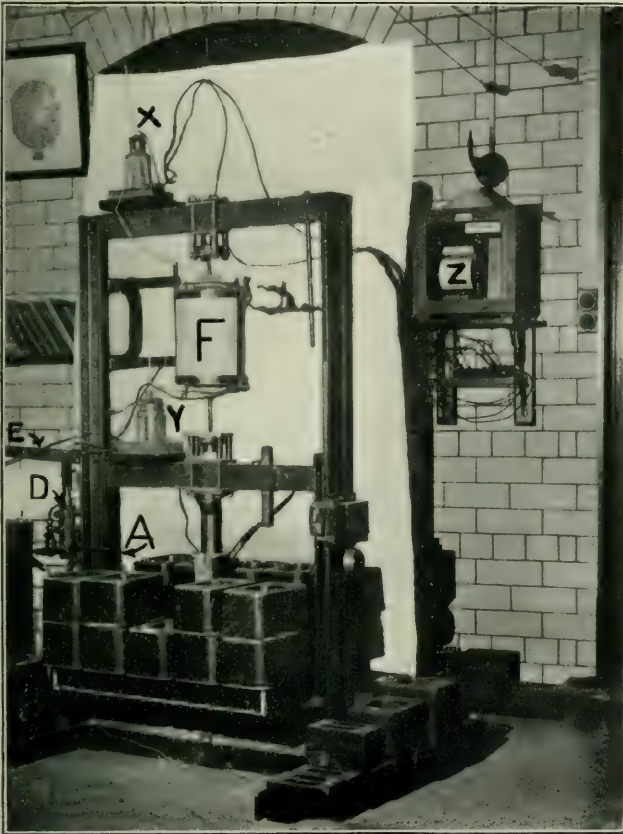
clear, but the author believes it to be of the form shown in Fig. 23. The dotted curve shows a possible variation where the elongation increases regularly from 0° .

The curves of several two-phase systems have been discussed in some detail already. It is, however, doubtful if we are yet in a position to give a complete explanation of all the types of curves obtained for these more complex cases. These types have not yet been sufficiently clearly fixed experimentally, and much more work will have to be done before they can be regarded as settled. The author only regards his results as affording a preliminary exploration of the field.

In conclusion, the author would like to draw attention again to the remarkable fact that the most abrupt changes in mechanical properties which have been found in the alloys examined do not occur at temperatures corresponding to phase changes, either in the case of pure metals or in the case of complex two-phase systems. It would appear that the presence of unstable and non-crystalline substances is the most important factor in determining the mechanical properties of metals and alloys at ordinary and moderate temperatures. If this reasoning be not accepted, then some cause other than phase changes must be sought in explanation of the remarkable experimental facts that have been now described. In the last May lecture delivered before this Institute, Beilby drew attention to the importance of amorphous, vitreous, and unstable substances in commerce, and instanced glass as a case in point; is it not possible that such substances are of equal importance in the case of all metals handled, used, or worked at any temperature removed by more than a comparatively short range from their melting points? If this be so, then the attention of metallurgists must in the future be concentrated much less exclusively on the study of stable systems than it has been in the past.

The author desires here to express his cordial thanks to the following gentlemen for their help in various ways: Mr. H. Jelf-Reveley, Mr. H. Purser (of Birmingham University), and Mr. Donaldson (of Liverpool University), the last of whom carried out most of the cold tests described in the paper.

PLATE XIV



KEY TO PLATE XIV. AND FIGS. 2 AND 3.

- A=Pipe from hydraulic cylinder to tap B.
- B=Tap to pipe from cylinder (Fig. 4).
- C=Reservoir (Fig. 4).
- D=Pump.
- E=Pump lever.
- F=Furnace.
- X=Thermocouple cold junction.
- Y=" " "
- Z=Thread recorder.

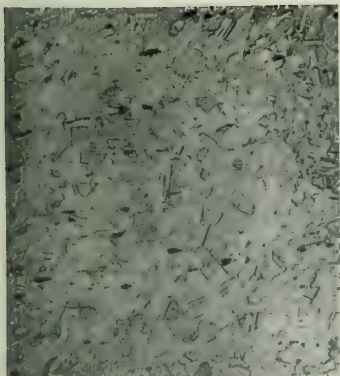


FIG. 1.—Copper (as rolled).

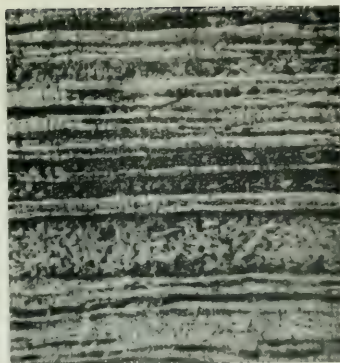


FIG. 2.—Cupro-nickel (as rolled).
Magnification 150 diameters.

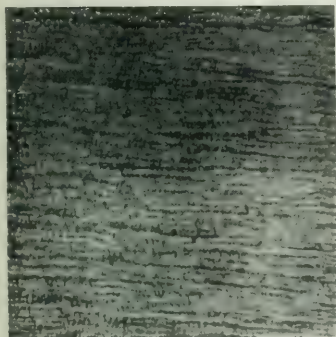


FIG. 3.—Cupro-nickel (annealed 1 hour
at 700° C.).

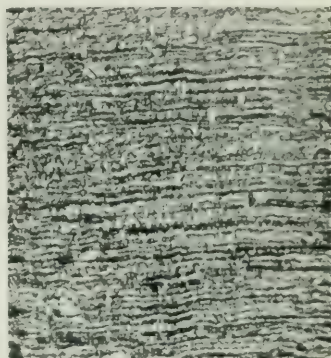


FIG. 4.—Cupro-nickel (annealed 1 hour
at 750° C.).

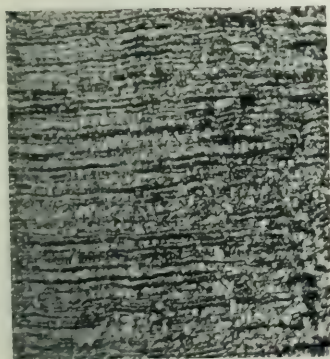


FIG. 5.—Cupro-nickel (annealed 1 hour
at 800° C.).

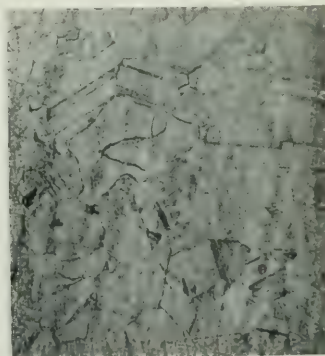


FIG. 6.—Cupro-nickel (annealed 1 hour
at 900° C.).

Copper etched with ammonia.

Cupro-nickel etched with hot hydrochloric acid.

Magnification 80 diameters in all cases except Figs. 2 and 13.

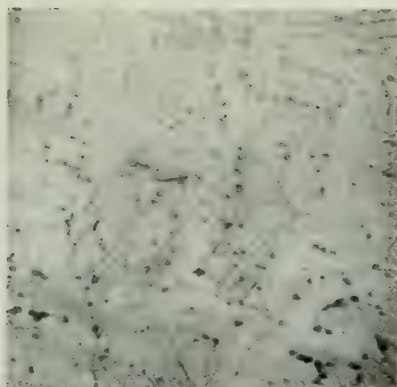


Fig. 7.—Cast Brass A. Broken at 785° C.
Near fracture.

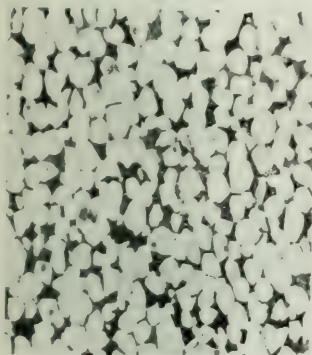


FIG. 8.—Muntz Metal A (as rolled).

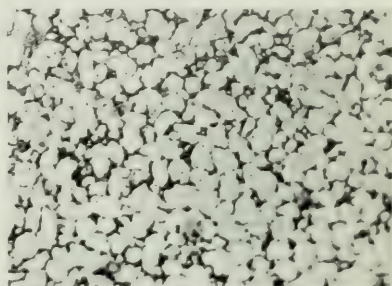


FIG. 9.—Muntz Metal B (as rolled).

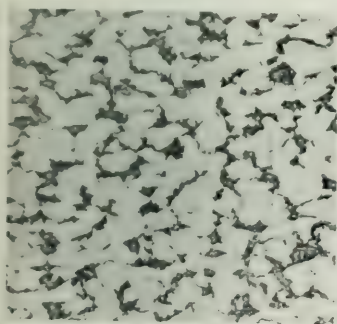


FIG. 10.—Muntz Metal B. Broken at 625°.

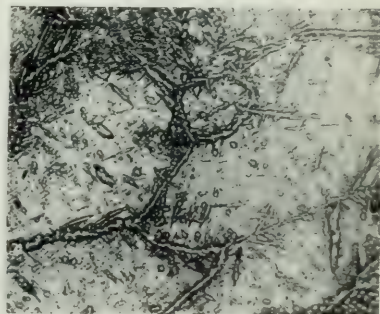


FIG. 11.—Brass C (as cast).

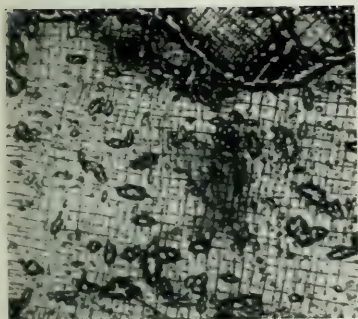


FIG. 12.—Brass C (as cast).
Magnification 150 diameters (deeply etched).

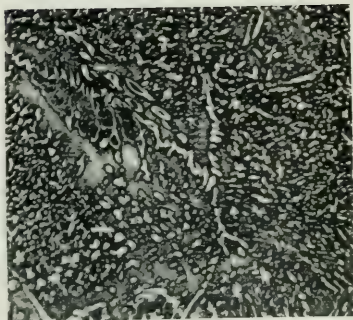


FIG. 13.—Brass C. Broken at 530°.

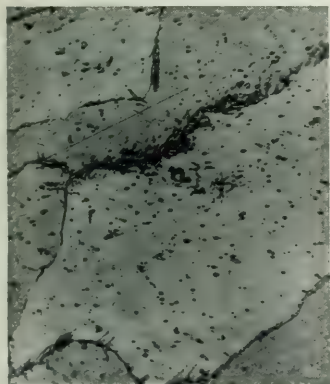


FIG. 14.—Brass C. Broken at 700° C.

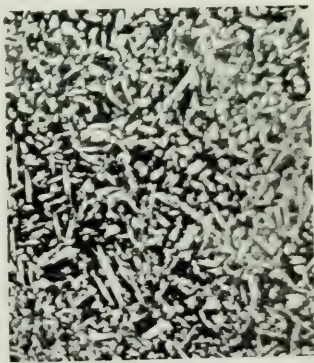


FIG. 15.—Complex Brass (as rolled).



DISCUSSION.

Sir GERARD MUNTZ, Bart., Past-President, in opening the discussion, said the paper was a very long one, containing a tremendous amount of material, and he therefore proposed to comment on only a very small section of it. As the author referred to Muntz metal in several parts of his paper, he felt particularly called upon to speak. First of all, he wished to attack the author for his use of the word "Muntz metal," because Mr. Bengough did not seem to know what Muntz metal was. Muntz metal "B" was not Muntz metal at all. Although it gave results very analogous to what lower-grade Muntz metal would yield, at the same time it was somewhat misleading to designate it Muntz metal. The analyses given for Muntz metal "A" were 60·52 of copper, 38·8 of zinc, and 0·4 lead. That might be taken as a reasonable quality of Muntz metal; but in Class "B" Muntz metal, given in the paper, there was 59·52 of copper and 0·39 of nickel, which had nothing whatever to do with Muntz metal. Mr. Boeddicker would probably tell the members more about that shortly. Then there was 39·43 zinc, which was a shade high, and 0·74 of lead. That would pass, but the percentage of copper was lower. Speaking for the Muntz Metal Company, they had always considered that anything below 60 per cent. of copper was not a true Muntz metal, and that percentage had always been reached in the metals supplied by the Company. He merely mentioned that in passing. It was very interesting to him, looking at the paper, to find, with regard to Class "B" Muntz metal, that the author arrived at the same conclusion from his scientific research that the Muntz Metal Company had arrived at after many years of practical knowledge, namely, the extraordinary difference in the elongation and ductility of what the author designated Class "B" Muntz metal—what he (Sir Gerard Muntz) would call soft metal. It was a well-recognised fact in his establishment, in the days before a laboratory was started, that if the Muntz metal which was rolled at high temperatures rolled remarkably easily, it raised suspicions in their minds that that particular batch of metal was what was called on the low side, *i.e.* contained too much zinc, because it rolled almost like butter. It was very soft, and it was possible to do almost anything with it. It did not break, and it did not give a cracked edge. With copper down to 58½ per cent., extraordinary ductility was obtained at high temperatures, much more so than was obtained in what his firm classed as good Muntz metal. On the other hand, with 61, 61½, or 62 per cent. of copper in Muntz metal, on hot rolling the reverse took place, and cracked edges were obtained on the sheet. It was therefore very interesting to him as a practical man to find that the author confirmed his experience in that respect. He had not previously discovered why that was the case, but the light the author had thrown on it was extremely interesting. Class "B" Muntz metal, which was not really Muntz metal at all, but something like it, had that peculiar property of increased power of elongation at certain temperatures. That brought

the β phase question a further step towards the point that had also been referred to of the amorphous metal between the crystals of Muntz metal and the β phase. It was a curious thing that that had been pointed out, because there was no doubt that when Muntz metal was worked subsequently at high temperatures an amorphous formation did not take place, and that the crystal formation was simple. He thought it was a fairly well-known fact that in the Muntz metal alloys, which were produced by the extrusion process, and therefore produced at very high temperature, the same results were not obtained as in Muntz metal that had been rolled hot. Although the process was started hot, the rolling was subsequently continued after the metal was down to a black heat, and therefore a certain amount of mechanical work was applied at that point. If the author's theory was correct, that amorphous substance was probably created which gave a different structure in the metal, and ultimately resulted in different action when the metal came to be put to work. His experience led him to the belief that a rolled rod would give ultimately much longer life and much better results than an extruded rod, because if a test was taken from the extruded rod, just as good a test would be obtained from it as from the rolled rod in the first instance, but something took place subsequently by the formation of crystals, which the scientific gentlemen present had largely explained, which rendered that extruded rod not so reliable as the rolled rod. It had always been somewhat of a puzzle, both to the manufacturer and to the user of Muntz metal and naval brass rods, why though the extruded rod, which gave such remarkable tests, sometimes superior to the rolled rod, was not, however, ultimately reliable, and was apt to crystallise out and to break off when at work. He thought the light thrown on that subject in the paper was of extreme value, and if followed out should be of great use. The defect could, of course, be easily overcome by subsequently putting mechanical work to a certain extent on the extruded rod. Probably a phase would then be obtained which was desirable, but the matter would repay still further research in the laboratory. There was a number of other points on which he could have spoken, but there were several members present who were more competent to speak on the copper question than he was, and he was looking forward to hearing something about nickel from another direction.

Dr. WALTER ROSENHAIN, Member of Council, said that the author's paper was an exceedingly interesting one, which embodied an enormous amount of work, and was full of suggestive ideas. Although appreciating it in that way, he had read it carefully and somewhat critically, and consequently he had quite a string of remarks to offer which he would not trouble the members with at present, with the exception of one or two points. For instance, with regard to the experimental part of the paper it was possible to offer objections of several kinds. The first was with regard to the method of testing in placing reliance upon the constancy of friction of an hydraulic ram. That was a principle which the makers of testing machines had long ago abandoned as impracticable. It would

be found that a testing machine was now never made in which the loading of the ram direct without some purely mechanical measuring device was used.

Mr. BENGOUGH said it was tested after experiment.

Dr. ROSENHAIN said he understood that, but it did not necessarily follow that it was right during the experiment. It was not a very safe principle, in his opinion. The next point to which he wished to refer was that he would have been very glad if the author had been able to devise some means of measuring the first sign of yield in the alloys. Even at the lower temperatures at which he and other people had worked, it had been found to be very difficult, but they had been able to do it up to 300° or 400° C. It was true that the curve of yield stresses rapidly approached the curve of ultimate stresses as the temperature rose. That was an interesting fact which emerged from the series of tests he had carried out, and it would be very interesting to see how far the author's much more complete tests bore that out. The main difficulty which he raised, because the author claimed that his paper was intended as an academic rather than a practical one, was the fact that the effect of oxygen on the alloys had not been taken into account. He knew the author was as well aware of that as he (Dr. Rosenhain) was, but at the same time, he did not seem to recognise it in discussing his results. The shape of the upper portions of the curves might be materially affected by the oxidation of the alloy on the surface, and the rapid spread of that oxide into the metal. The time during which those alloys were kept hot was very considerable, and errors from that cause were possible. In discussing the matter from the purely theoretical point of view that source of error would have to be considered. He knew the author intended to make experiments with that point in view, and he would be interested in seeing the results that were obtained. Finally, the method of using the constant time of test appeared to him to be fundamentally undesirable. Would it not have been better to have kept the alloys for a definite time at the temperature at which they were to be tested, and then to have loaded them at a constant rate? His reason for saying that was that he had strong evidence for believing that when alloys got near their melting point the rate of loading had a very vital effect—in fact it came in even at temperatures like those shown on Professor Huntington's diagrams. He had made one or two experiments himself, and found that very different curves could be obtained according to the rate of loading adopted. The question of the spontaneous annealing came in. The kink in the curve shown would have been very materially displaced at a different rate of loading. The author's rate of loading was not constant, so that it was impossible to know exactly what was represented by these curves. He did not intend to go into the whole of the theoretical question, but he desired to draw the author's attention to the fact that the question of the strength of the intercrystalline boundary had received a certain amount of consideration.

Personally he discussed the matter pretty fully in a paper read before the Iron and Steel Institute in 1904, when he advanced a theory which was not very different from the author's. Since then he had come to exactly the same conclusion which the author had reached, although he had not published it, namely, that there must be an amorphous cement between the crystals. But he went much further than that. He disagreed with the author's idea that the amorphous cement could not exist at high temperatures. He thought it existed in the inter-crystalline boundary, because there was a limit to the scale of crystallisation. There was good reason for believing that crystals were built up out of units, or "bricks," which were large compared with a molecule; where two crystals came together, minute quantities of matter would be left in the interstices between the differently oriented units, and since these minute quantities of matter were too small to form further crystal units, they must necessarily remain in the amorphous condition, and their existence was independent of temperature. He asked the members to consider what the amorphous substance was. The closest analogue to it was glass, and that softened very gradually, and became extremely ductile at high temperatures. If a curve of the tensile strength of glass was plotted, and if a curve was plotted of a purely crystalline substance in which there was no amorphous matter at all, he thought it would be found that the two curves added up would give something very similar to those shown by Mr. Bengough. The change of shape of the curve was due to the fact that the inter-crystalline cement became a viscous liquid at the higher temperatures, and that the deformation took place by the flow of the cement. That was a slight modification of the author's views, but fundamentally the idea that there was such an inter-crystalline cement appealed to him very strongly. He had many lines of evidence on different grounds, which were not sufficiently complete yet to enable them to be published, which bore that out, and as the author had put forward the idea he thought it only right to mention that other people were at work on the subject also. As a matter of fact, he discussed the idea with Dr. Beilby a great many months ago, and it appealed to that gentleman very strongly. He put it to Dr. Beilby in order to have the benefit of his views on the subject, and he hoped he would have an opportunity of being able to further deal with the matter.

Professor T. TURNER, M.Sc., Honorary Treasurer, said that although there might be differences of view in matters of detail in connection with the carrying out of the author's experiments, he felt sure all the members had read the paper with very great interest. He regarded the work as being very carefully designed, and on the whole as being admirably carried out. He was particularly interested in the question of the general theoretical conclusion, which was represented diagrammatically on page 167, to which Dr. Rosenhain had already briefly referred. He thought the members were much indebted to the author for his expression of view on that point.

The author showed that on examining the tensile strength, and start-

ing from the melting point, there was one portion of the curve which was steep, and in which the tensile strength increased very slowly. During that period if the metal was strained it recrystallised, either almost completely, as Dr. Rosenhain suggested, or completely, as the author had led them to suppose from his diagram. That portion of the curve comprised what Roberts-Austen called the "semi-solid state" in metals. It comprised what he (Professor Turner), for want of a better term, had also described as a semi-solid state in metals, where the metal was quite plastic and could be squeezed and deformed without leaving any marks of the worked hardness.* He knew that their chemical friends objected to the words "semi-solid state," and he knew, from some conversation he had had with Dr. Rosenhain, that Dr. Rosenhain strongly objected to that phrase. Personally he only used it because he had not a better; and if some one could suggest to him a term which would more correctly describe the properties of metal from the point X to the point Y on Fig. 22 in the paper, he would be very glad to use that better phrase. In the next place he wished to refer to the tensile strength of worked metal, which, Mr. Bengough had shown, gradually fell as the temperature rose. He had long tried to explain the cause and limits of worked hardness, and he believed the author's diagram helped them to understand what the hardness due to work was.

Another curve, the YCZ curve, was given by the author in that connection. Now why was that worked hardness obtained? Owing to the production of the inter-crystalline strained material which was amorphous. That could only be produced by the action of work as between crystal areas. If it was imagined that two crystalline masses were forced to slide over one another within the range of temperature corresponding with the line YAW, then an amorphous material was produced which gradually increased in quantity as the work was continued. But if the supposition was made that a stress was put upon any crystal area which was greater than the crystal strength, or, in other words, greater than the original tensile strength of the cast material, then the crystal would break. Hence the limit of worked hardness was that it was never possible by cold working to more than double the tensile strength of the material in the cast state. This follows from the fact that it is never possible to entirely remove the whole of the crystalline material by work. The author's typical curve was not quite correct at the top; it was a little too wide from Y to C. If once a greater tensile strength was put on the intermediate crystalline parts than the crystal could stand, fracture would take place through the crystal. There might be exceptions to this general rule, that cold working did not more than double the tensile strength, although he had examined a very large number of cases both in iron and steel and in non-ferrous alloys, and had not found such an instance. If one desired to get a very high tensile steel wire, say, of 120 tons per square inch, it was no good starting with a mild steel; it was necessary to start with

* See paper, "The Semi-Solid State in Metals," South Staffordshire Iron and Steel Institute, January 1904.

a high tensile steel, and then it was possible to double the strength. The same remark applied with regard to many of the other alloys. The author's diagram was broadly true, if it was not accurately so, in practice, and if it was fully substantiated it would be of very great interest in the future. He knew that previous workers on the influence of temperature on the tensile strength of mild steel had given an almost exactly similar diagram to that represented by the line XYZ.

Professor H. C. H. CARPENTER, M.A., Ph.D., Vice-President, desired to add his tribute of admiration to those which had already been expressed by the previous speakers to the author for his interesting and suggestive paper. He viewed it, as the author had asked them to do, as a pioneering paper, and therefore as one in which finality was not to be anticipated. As illustrating that, he would like to refer to the diagram on page 167. Under some circumstances, although he did not say they were usual, the line YBV could approach YCZ, and even pass it. That he would prove. In the case of the so-called aluminium-bronze with 9.9 per cent. of aluminium, Mr. Edwards and he, in the Eighth Alloys Report showed that a chill casting 1 inch in diameter and 7 inches in length had a tenacity of 36.93 tons per square inch, and an elongation of 30.5 per cent. on 2 inches. For rolled material the dimensions of the original casting were 3 inches by 20 inches, and that was rolled down to a $1\frac{1}{4}$ -inch bar. The latter gave an ultimate stress of 35.03 tons per square inch, and an elongation of 31.5 per cent., *i.e.* the rolled material was very nearly two tons weaker than the chill casting. On the other hand, if the bar was rolled further down to $\frac{1}{4}$ inch, the ultimate stress went up to 38.1 tons at a slight expense of ductility, *viz.* 28.8 per cent. So that with a reduction of area of 80 per cent. of the original casting, the tenacity of the rolled bar was only 1 ton in excess of that of the chill casting. So that it might be said that the author's drawing, while it no doubt represented the majority of cases, must not be pushed too far—that in certain circumstances cast material was as good as rolled. He thought it was quite easy to understand why that was so. In the case to which he referred, a test-piece cut from the centre of a 3-inch diameter casting was inferior to one cut from the outside, and the reason for the mechanical work of rolling, &c., was the necessity of getting rid of the stresses set up in the interior of the casting. If the size of the casting was suitably chosen and it was of simple form, it was possible under certain circumstances to get a chill casting which was as good as rolled material. He wished also to refer to the author's theory on pages 168 and 169. He did not wish to express any definite opinion as to that at present, because he thought more evidence on the point was required. He thought, however, that what evidence was available went to show that Dr. Rosenhain was right in thinking that the amorphous film did not disappear even at high temperatures. A paper had recently been published by Wark on the "Polyhedral Structure of Iron-Carbon Alloys at High Temperatures."* He imagined that as the temperatures were

* *Metallurgie*, 1911, pp. 731-36.

between 1100° and 1300° C., they would probably be well above the recuperation temperature to which the author alluded. The interesting point was that the boundaries of the crystals etched at these temperatures were even wider than at the ordinary temperature. That went to show, taking the author's interpretation, that the amorphous film round the crystals did not disappear at high temperatures, but if anything increased.

Dr. ROSENHAIN inquired how the specimens were etched.

Professor CARPENTER replied that they were etched by hydrochloric acid.

Professor TURNER said it was not pure metal.

Professor CARPENTER, continuing, said that with a mild steel the author was able to get a pure polyhedral structure with deep boundaries without a trace of martensitic marking. That, he thought, was a fact which bore on the matter under discussion. He suggested to the author that it would be interesting as testing his own theory if he would etch one of his alloys in the area above the recuperation temperature. While on the point, he desired also to ask him whether he regarded the recuperation temperature as an actual point. Was it confined within a comparatively narrow area of temperature, or was it spread over a range? Finally, the author had asked for his (Professor Carpenter's) opinion on Fig. 17 on page 158. There the members would notice that just between 450° and 500° relatively enormous variations in ductility were obtained. That was just what one would expect in a material which underwent the constitutional change from $\alpha + \gamma$ to β in that temperature range. The variations fitted in with the constitutional and structural change in the material, and that was why he thought the author would always have difficulty in drawing a smooth curve through a material in that range of temperature, because a slight difference in the extent of the change would make a considerable difference to the properties. It was interesting that the author's Muntz metal curve, shown on page 155, did not show that variation in properties at that temperature. In that case the variation occurred between 350° C. and 400° C. He would like to ask the author for his explanation on that point.

Mr. G. A. BOEDDICKER, Member of Council, said that the alloy which had interested him more than any other described in the author's interesting paper was the 80/20 cupro-nickel. Looking at the curve on page 158 he was absolutely convinced that this was not the typical curve on cupro-nickel at all. From the analysis given on page 141, which added up to 100 per cent., he concluded that one of the constituents had been taken by difference, and he thought it was very dangerous to draw conclusions from any analysis where this was the case. Copper-

nickel alloys were very difficult alloys to deal with. There were two special difficulties, the first being the presence of oxygen, which rendered the alloy practically useless, and secondly the presence of carbon. Oxygen was removed by a deoxidising agent, manganese, ferro-manganese, copper-manganese or magnesium, and the analysis certainly should have shown traces of manganese or magnesium. With regard to the presence of carbon, that up to a certain percentage would be present as combined carbon, and, if anything, would improve the working qualities of the alloy while worked cold, but as soon as the alloy was heated to 650° or 700° , especially over a lengthy period, the carbon, which up to that temperature had been chemically combined, began to segregate out as graphite. He had had hundreds of cases of that kind, where 25 per cent. cupro-nickel had been made into coinage blanks. Before being sent to the Mint they were annealed, and on arrival at the Mint hundreds of blanks were found broken into small pieces, and in every case on dissolving the broken pieces in nitric acid, large flakes of graphite were found in the solution. He thought the elongation curve should be a continuous one—in other words, the elongation should slowly decrease till about 600° , then increase steadily until the temperature near to the melting point was reached. Looking at the curve as given in Fig. 11, page 158, it seemed to him that the specimen of cupro-nickel tested must have contained a slight amount of carbon. The elongation began to increase at about 650° , but at 700° there was a sudden set-back, which seemed to him to indicate that at that point the carbon, probably a very small quantity, segregated out as graphite, that at the further rise in temperature, either the carbon was reabsorbed (which he doubted, because he had made many experiments in that direction without result), or the percentage of graphite was so small that the greater elongation caused by the higher temperature counteracted the action of the graphite.

In his opinion a great many more experiments with the 80/20 alloy should be made, and should be in every case accompanied by a full analysis, giving the oxygen, carbon, manganese, and sulphur present.

Mr. O. F. HUDSON, M.Sc. (Birmingham), desired to say, in the first place, how much he admired the author's work both experimentally and in regard to his conclusions and generalisations. He thought, however, in regard to the temperature of recuperation the author had not perhaps sufficiently considered the question of the recrystallisation taking place at that temperature. So far as he remembered, in dealing with 70/30 brass it was just about at that temperature active recrystallisation set in. Annealing up to the temperature of 400° , which was near the temperature of recuperation, the crystalline growth was not very marked, but when annealing at a slightly higher temperature recrystallisation began, and above that went on very rapidly indeed.

There was one other point to which he wished to refer with regard to the straight line YV of Fig. 22. The author did not appear to have considered very much the question of the strength of the annealed

metals. In the paper the cast metal and the hard-rolled metal were compared. He desired to suggest that the properly annealed metal would be perhaps a better standard for comparison than the cast metal. In a cast metal very much more serious internal strains had to be dealt with, whereas he thought a much more ideally crystalline material would be obtained if a properly annealed metal were used. With regard to the amorphous phase, which acted as a strengthening cement between crystals, it was difficult to realise the important part which it might play. The trouble was that it was impossible to handle that amorphous modification, and yet it was spoken of as occurring in large or small quantities. He had an idea that the amorphous phase could not exist except in the minutest film, and he thought that was in accordance with the view that Dr. Rosenhain had expressed. The cement was only, as it were, a very small residue of molecules that was between the crystals or between the cleavage planes. The quantity between any particular cleavage plane was not increased by further deformation; they only increased the quantity by increasing the number of cleavage planes or the number of crystal junctions. It could exist there only as the very minutest film. Finally, as a question of detail, he wished to refer to the "cry" of the metals when they were tested at high temperatures. He could not speak from experience except of 70/30 brass, but he had noticed that in bending a wire the "cry" was very distinct and very noticeable. He, however, only noticed it distinctly at the temperature of recuperation or about that temperature. At higher temperatures the "cry" was not noticeable. It was just at that temperature that it cried very distinctly; below or above, it was not so distinct.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), said the paper that the author had presented was full of interest, and one that must make its mark on the work done on brasses. He wished to confine his remarks to one or two points in connection with the crystallisation of the metals as included in the explanation that formed the latter half of the paper. If the deductions drawn in the paper held strictly true, *i.e.* that the cry of metals referred to was due to the complete recrystallisation of the metal, that cry should be present in annealed specimens of materials that were of uniform composition; and the question as to whether annealed metals that were perfectly crystalline would cry, should determine whether the cry was due to the passage of what had been described as amorphous matter into the crystalline condition. The question of the amorphous matter was a point to which he wished to direct some attention. Throughout the discussions it had been taken for granted that the recrystallisation of the material arose from the attraction of the material existing in the amorphous condition to the already existing crystals. He would like to point out that the property of crystallisation was independent of existing bodies—was resident in the particles of the substances themselves, and the form that was taken and the way in which the crystal was built up was only determined by the conditions by which it was surrounded. So that the formation of crystallites, rods,

and skeleton crystals, and the filling up of those skeleton crystals was followed in regular order, but in strict obedience to the characters of the material itself. It would appear therefore that if any uncrystallised material were left between the crystals of a body that had, in the main, assumed a crystalline state, that such material was only in a state of confused crystallisation, and had not been able, for mechanical reasons, to adjust itself to the forms by which it was surrounded. Planes of weakness were met with in castings resulting from the crystallisation in different directions intersecting in certain planes. If the amorphous matter were stronger, and if it were due to the cause assigned, those planes should be actually planes of strength, whereas as a matter of fact they were invariably planes of weakness. So that the possibility of the material existing in an amorphous condition as the result of imperfect crystallisation was, he thought, not particularly clear. Another point on which he desired to speak was that if the amorphous material were truly amorphous, its change to a crystalline state could only take place at the temperature of recuperation, and consequently the strength, if due to that amorphous material, should not be reduced until the temperature of recuperation had been attained.

There were sundry other points with which he would probably deal in a written communication, and he would therefore conclude by again expressing his great admiration of the paper.

The CHAIRMAN, in concluding the discussion, said that the author had already referred to his (the Chairman's) curves on the wall (see Figs. 1 and 2, p. 185), and he therefore did not propose to detain the members long by going into them in detail. The only point on the curves which poached on the author's preserves was the last point on the reduction of area curve, and the corresponding point on the elongation curve. That corresponded to the change in the curve which the author called the recuperation point. It was the only one that went up high; it was lower than in the author's diagrams, but it was obviously the same point where the curves turned round. He had several more curves which had been made since, one for arsenic-copper containing about 0.28 of arsenic, and another for nickel-copper; and, with the approval of the Council, he hoped to offer a paper later on which would deal with those curves from another point of view than that with which the members were dealing at the present moment. The only other point he wished to refer to was in connection with the diagram that was made two years ago (see Fig. 3, p. 186). The following was the procedure adopted in testing this bar of complex brass for "plasticity" on 12th to 20th November 1909. The original length of the part tested was 2 inches, and the original diameter 0.797 inch.

After fixing the bar in the testing machine, it was heated and the temperature adjusted to keep constant at the desired temperature throughout the test. A suitable load was then applied to the bar, and the elongation attained during the first minute was recorded. At the end of about five minutes the bar was again measured, and if no further

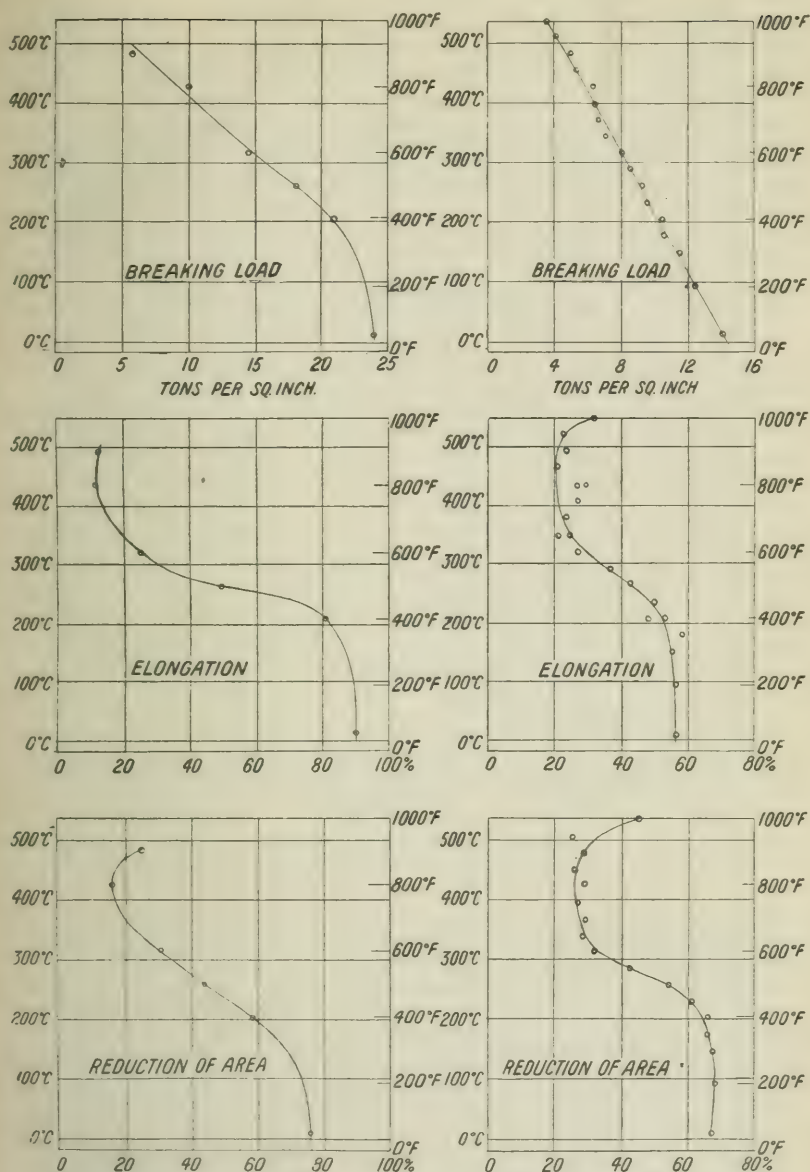


FIG. 1.—Aluminium-bronze.
December 7, 1900.

Aluminium	. . .	7.15 per cent.
Iron	. . .	0.115 "
Silicon	. . .	0.027 "

FIG. 2.—Annealed Electrolytic Copper.
March 13, 1906.

Arsenic	. . .	Trace.
Antimony	. . .	Nil.
Bismuth	. . .	0.0005 per cent.
Selenium	. . .	Trace.
Tellurium	. . .	"

elongation (0.002 inch) was observed, the load was kept on for a further ten minutes, when the elongation was again measured. If no increase was observed, the bar was taken as "not plastic," and the load was increased. If any elongation was observed during the first five minutes, the bar was measured twice again in intervals of five minutes, and the elongations taking place over the three separate five-minute intervals were compared, and the bar was taken as plastic if the five-minute elongations increased with time. Similarly, if elongation was observed on fifteen minutes but not on five minutes, two measurements at fifteen-minute intervals were taken, and the bar taken as plastic if the fifteen-minute elongations increased with time. The load was then decreased. The above procedure was repeated until two loads differing by about

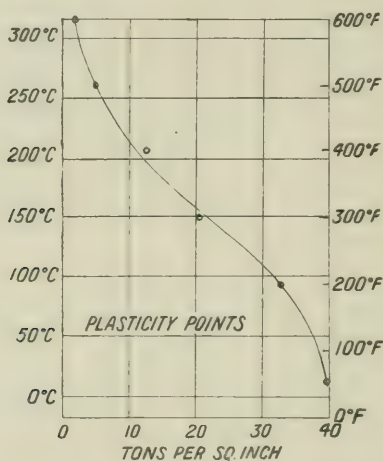


FIG. 3.—Complex Brass.
April 7, 1910.
Zinc about 40 per Cent.

$\frac{1}{2}$ ton per square inch were obtained, such that the bar was plastic at the higher load but not plastic at the lower one.

The work from which the curves were plotted was carried out with very great care, and, so far as it went in that particular region, he thought it confirmed what the author had done. The curves did not go up into what he might call the author's special region. The region below with which he (the Chairman) dealt was a region which the author had not explored at all fully, whereas the region above he had explored in a way that no one else had ever done. The credit in that region was entirely the author's. It was exceedingly difficult to carry out such tests at very high temperatures. Those who were acquainted with the making of tests could easily imagine the difficulty of making tests at such a high temperature in a special electric furnace, so that

the members were very greatly indebted to the author for the trouble he had taken in what was not merely a scientific research, but one which had many practical bearings.

Mr. G. D. BENGOUGH said that so many points had been dealt with in the course of the discussion that, with the permission of the members, he would reserve the whole of his reply, sending this to the Editor for publication in the *Journal*.

COMMUNICATIONS.

Mr. C. O. BANNISTER, Assoc.R.S.M. (London), wrote that Mr. Bengough's results should prove very useful in many directions, and the fact that the author had carried out his tests at temperatures hitherto unattempted was a noteworthy feature of the work. The question of the strength of metals and alloys at high temperatures was becoming of considerable importance, and had not up to the present received the attention it deserved. The manner in which the curves have been plotted in the paper did not seem to have caused any comment in the discussion, although it would appear that the author had been somewhat erratic in that portion of the work. Taking, for example, the elongation curve for aluminium on page 147, in plotting that curve the author had left out the result obtained at 396°C . By drawing the curve through that point, the result obtained would be in agreement with the maximum stress curve on page 146, and the well-marked break in the stress and strain curves would be seen to occur at the same temperature. Similar remarks applied to the elongation curve for copper, for by averaging the results obtained between 600°C . and 900°C . a very much simplified curve might be obtained equally well representing the results given.

This simplification of the author's curves might also be applied to many of the others given, especially the elongation curve of brass C and that of the complex brass.

Dr. C. H. DESCH (Glasgow) wrote that Mr. Bengough's work represented a great advance on previous work on the dependence of mechanical properties on temperature. Although the testing machine employed was not of a very delicate kind, the precautions taken to ensure uniformity of temperature—the chief difficulty in tests of this kind—seemed to be satisfactory, and the general accuracy of the form of the curves could be safely assumed. The most interesting fact observed by Mr. Bengough was the existence of a well-defined point which he called the limit of complete recuperation. The distinctness of this point on the maximum stress-temperature curves was evidence of the care with which the tests were made. As regards the explanation of that point, the suggestion that it represented the upper limit of existence of the amorphous modification was exceedingly interesting. There were, however, certain difficulties in the way of its acceptance. The rate of passage

of amorphous into crystalline material, that is, the velocity of crystallisation, varied with the temperature in a manner that had been determined in a number of cases by Tammann,* and there was usually a range of temperature within which complete crystallisation could take place, but with a velocity varying with the temperature, and probably passing through a maximum at some point. If this held good for metals and alloys, it would lead one to expect that the time of loading would have a great influence at temperatures somewhat below the "recuperation" point. The time factor was certainly of great importance in these cases, and further experiments in that direction would seem to be required. The observation of the "cry" at high temperatures was also very interesting. Here, again, certain difficulties suggested themselves. For instance, lead was generally assumed to be incapable of conversion into the amorphous form at ordinary temperatures, owing to the impossibility of hardening it appreciably by mechanical means, and it should therefore be, on the author's view, above its recuperation temperature, but it did not give out a "cry." Several of Dr. Beilby's curves were also not immediately reconcilable with the view that the amorphous modifications of metals were capable of persisting at such high temperatures. This, of course, did not mean that the explanation proposed could not be accepted, but only that further research was required to fix the limits of existence of the amorphous modification, the discovery of which by Dr. Beilby had done so much towards explaining the mechanical properties of metals. Mr. Bengough's research marked another step towards a complete explanation.

Mr. R. M. SHEPPARD (Birmingham) wrote that he noticed the author referred to the mechanical effect of the inversion at 475° C. discovered by Carpenter and Edwards. He was surprised that no distinct effect was observed in the sample marked Muntz metal A. In sample B there was an uncertain effect according to the elongation curve, but readings at this point seemed to be very variable. He would expect a very marked falling off in the elongation at the temperature 475° , as in actual practice it was found that alloys of the Muntz metal type were extremely brittle at about that temperature. For instance, a sheet of Muntz metal could be shattered to pieces by hammering at that temperature, and large rolled bars several inches in diameter could be broken easily with a moderately heavy hammer in one blow. The elongation therefore at this critical temperature one would expect to be approximately zero.

Referring to the low elongation of aluminium castings as mentioned by Mr. Bengough when reading his paper in London, he (Mr. Sheppard) thought that there was nothing very extraordinary about the results obtained, as pure aluminium was very unsuitable for casting in sand, and it seemed impossible to obtain an elongation of more than about 2 per cent. Even with the aluminium castings supplied for motor car

* *Krystallisieren und Schmelzen*, Leipzig, 1903, p. 148; *Zeitschrift für Elektrochemie*, 1904, x, 532.

work, most of which contained from about 2 per cent. to 4 per cent. of copper, and from 10 per cent. to 20 per cent. of spelter, the guaranteed elongation was generally below 5 per cent. A few expensive alloys, made with some rarer element, such as vanadium, gave better elongations. The low elongation of aluminium castings was evidently partly due to oxide, and it also appeared to be largely influenced by the quantity of silicon in the metal; appreciable quantities of that element being often present in the form of silica, which had a bad effect on the mechanical properties of castings.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), wrote that this paper, with the modifications contemplated in further research by the author on page 145 (second paragraph), was of the greatest interest to manufacturers and users of non-ferrous metals and alloys.

As showing the interest of the paper to the practical man he instanced the results of the tests on copper. The practical roller was aware that his charge of cakes or ingots must be raised to "a good heat" before he placed them between the "breaking-down roll." He might even (and sometimes did) regulate his reheating furnace to temperatures between 800° C. and 900° C.

Mr. Bengough proved that a temperature of 800° C. in the furnace and 750° C. at the rolls was the safest "heat" for the hot rolling of copper, that an inflame and cheaply constructed furnace was unsuitable for consistent work and regular temperatures, and oxidation of the charge should be prevented.

With copper-nickel alloys even closer hot-rolling temperatures were necessary than in the case of copper.

In regard to the brasses, much useful information for works' practice was given.

As to the results in general, he (Mr. Hughes) would inquire of the author whether he ought not to establish beyond doubt the inward bend of the elongation curves at about 850° C. for copper, 750° C. for copper-nickel, 500° C. for cast brass, and 480° C. for the complex material. The reduced elongations indicated by the curves appeared to be due to the absorption of oxygen. The results obtained by the author were, doubtless, those prevailing in ordinary practice. But it would be very interesting to learn the results of further tests in an inert atmosphere. He had verbally suggested to the author the use of nitrogen prepared from the air by oxidising admixed ammonia gas over red hot copper, asbestos, or brick, the ammonia being carefully purified. The inert gas should be delivered *hot* (*i.e.* at the temperature of testing) into the upper portion of the heating appliance, and so remove the air surrounding the test-piece by downward displacement, continuously maintained.

He anticipated some interesting departures in the shape of the load-temperature and elongation-temperature curves for the same metals and alloys used in the recorded experiments.

It would also be well to purchase on the open market the samples of various metals and alloys (such as are supplied to the trade by well-

known makers) used for future tests. The production of castings or alloys in the laboratory was fraught with difficulties, and accompanied by defects which did not exist in a large melting shop or foundry under manufacturing conditions. Also, the use of purchased commercial material would end an undesirable type of criticism derogatory to the best interests of the users of non-ferrous alloys.

[EDITORIAL NOTE.—Owing to unforeseen circumstances it is impossible to publish Mr. Bengough's reply in the present issue of the *Journal*; this reply is consequently held over until the next issue of the *Journal*.]

A NOTE ON THE NOMENCLATURE OF ALLOYS.*

By WALTER ROSENHAIN, B.A., D.Sc. (MEMBER OF COUNCIL).

THE object of this note is to draw attention to the confusion which exists at the present time in the nomenclature of alloys. This confusion is so great that unless one is definitely acquainted with the composition and properties of the material sold or described under any given name, that name conveys no indication of the true nature of the alloy—in fact in some cases the name is definitely misleading. This does not apply so much to the well-known alloys such as “Muntz metal” and “naval brass” and similar alloys, but when an alloy consisting essentially of copper and zinc and containing not more than 0·2 per cent. of manganese is described as “manganese bronze” the need for some reform of nomenclature becomes evident.

The confusion to which reference has just been made is, perhaps, most strongly marked in the copper alloys, where no clear line of demarcation exists between such terms as “brass” and “bronze.” The alloys containing copper, zinc, and nickel, some of which are known as “German silver,” also represent a group in which much confusion exists. The alloys of aluminium with copper present a similar difficulty; the heavy alloys rich in copper are frequently termed “aluminium bronzes,” but if the term “bronze” is taken as implying an alloy consisting principally of copper and tin, this name is misleading when applied to a simple copper-aluminium combination.

It is not proposed in the present paper to lay down any definite proposals for a uniform and systematic nomenclature of even the copper alloys; the plan suggested by the author is rather to appoint a strong Committee of representative Members of the Institute concerned with the various classes

* Read at Annual General Meeting, London, January 17, 1912.

of alloys, and to set them the task of evolving such a system of nomenclature if possible in such a way as to be generally acceptable. In the present note it is merely proposed to put forward certain fundamental suggestions in a tentative way to serve as a basis for discussion; these tentative suggestions will be confined to the alloys of copper in which that element is the chief constituent.

The principle on which the suggested system of nomenclature is based is that of regarding alloys as essentially binary alloys—*i.e.* as consisting of two metals principally, to which one or more other metals may have been added in certain cases. Each of these groups of fundamental binary alloys should receive a general class-name, the various members of the class being then distinguished by the addition of certain words or syllables to the class-name. For the two most important of these classes general names are already in universal use. The whole class of copper-zinc alloys and their ternary and quaternary derivatives would, on this system, be termed “brasses,” while the class of copper-tin alloys and their derivatives would be called “bronzes.” The class of alloys having a basis of copper and aluminium is not so readily named, since the term “aluminium bronzes” is inadmissible on the principles suggested above. Perhaps the best course would be to adopt an entirely new name compounded of the words copper and aluminium, or parts of those words, or a word analagous to “brass” and “bronze” might be formed. Similarly, copper-nickel alloys might receive a simple, monosyllabic class-name. On the other hand, if the coining of new class-names is considered undesirable—and there are always grave objections to the coining of new words—the classes of alloys in question might be called by the names of the constituent metals—*i.e.* cupro-aluminiums and cupro-nickels.

For the majority of commercial alloys classification under these groups would be quite simple, since in most of these materials the approximation to one or other of the binary types is fairly definite. Thus “naval brass” would, strictly speaking, become “tin brass,” but in such a case the old name would be sufficiently near the systematic name to need no interference. Such an alloy as “aich metal,” consisting of 60

per cent. copper, 38·2 per cent. zinc, and 1·8 per cent. iron, would become simply an "iron brass," and brasses containing large proportions of lead would be termed "lead brass." This system is readily applicable to all those alloys which are essentially either brass or bronze (in the sense defined above), with moderate additions of other metals. A more difficult case arises in such an alloy as that, for example, known as "electrum," containing 51·61 per cent. copper, 22·58 per cent. zinc, and 25·81 per cent. nickel. Strictly speaking, this would be a zinc-cupro-nickel, but it might be more convenient to call it a nickel brass. A large number of alloys could be quoted which contain two metals (in addition to copper) in nearly equal proportions, and it would not be an easy task to decide to which of the fundamental binary systems such an alloy belongs, but by considering its properties and possibly its microstructure, its analogy to one or other group might be determined; in any case the system of nomenclature would be elastic enough to allow the alloy to be named by either of its constituents without causing misapprehension.

Having put forward these very tentative suggestions in the hope that a comprehensive and satisfactory system may ultimately be evolved, it remains to touch on one further point.

It is obviously outside the scope of this Institute, as it is outside the aims of the present note, to suggest or recommend the suppression of trade names of alloys of special properties, some of which hold the rank of recognised trade names and in some cases even of trade marks. The use of what one may term "fancy" names for the sale, and more particularly for the introduction of novel alloys of special properties, is no doubt necessary and useful for commercial purposes. Where such names are purely trade names, not descriptive of the composition of the alloy, their use in no way conflicts with either technical or scientific interests. On the other hand, where such names give what purports to be a description of the alloy by using such terms as "brass" or "bronze" qualified by the name of another metal, then it is essentially in the general interest that such descriptive names should not be misleading. At present there is no recognised system of

nomenclature for technical and scientific purposes, and no one can be blamed for applications of these terms which are really inconsistent with one another. The object of the system of nomenclature suggested here, or rather the system which it is hoped the Institute of Metals might evolve, would not be to introduce exact technical names into general commercial use so much as to provide the engineer in drawing up his specifications, and the analytical chemist in testing material under those specifications, with a clear and unambiguous set of names by which the general types of alloys could be distinguished. At present there is no unanimity whatever in these matters, and if this Institute could furnish such a basis, the interests of all concerned in alloys would be served.

DISCUSSION.

Mr. A. E. SEATON (Member of Council), in opening the discussion, said he desired to second the author's suggestion that the Institute should devote its attention in the immediate future to establishing some sort of nomenclature for copper and other alloys in order that there should be a clue to what was meant when they were named. He thought the suggestion that a committee should be appointed was an excellent one, and if the author moved a resolution to that effect he would second it. He spoke somewhat feelingly on the subject, because some years ago he undertook to supply a certain railway company with a ship which was to have propellers made of manganese bronze. The superintendent engineer of the railway company was somewhat critical, so he had the bronze analysed; much to his (Mr. Seaton's) surprise, he was informed that the company would not accept such blades, as they were not of manganese bronze. Now metal for the blades was obtained from a company which professed to make manganese bronze, so he did not quite understand how the analysis could have proved the absence of manganese. It was stated by the analyst that there was only a trace of manganese, while books said manganese bronze should contain more than a trace of manganese; in fact, a considerable quantity of it. The rejection of a good many hundred pounds' worth of propeller blades, all on account of a name, was a serious matter, and, after all, though the metal was not what was named, it was very good, for no fault could be found with its mechanical properties for propeller blades. But there it was; it was purchased as manganese bronze, but the buyer would not take it as such. He quite agreed with everything the author said in his paper, but admitted there was no doubt a very great difficulty in dealing with such matters. He presumed, however, that Mr. Bengough had had very great difficulty in dealing with some of the things to which he had referred in his paper, and Professor Turner and our other friends had also, but that had not deterred them, and would not deter them, from continuing their investigations. To put the suggestion into a practical form, if Dr. Rosenhain's suggestion was taken as a proposition, he would be delighted to second "that the Council be called upon to nominate a strong committee to deal with the whole subject of the nomenclature of bronzes and brasses and determine the composition of alloys that they may be included in the class claimed for them," because he thought it should be, if it was not already, one of the functions of the Institute of Metals to remove difficulties of this kind. If the problem was properly tackled, he thought the difficulties would be found after all to be much less than was imagined.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), in supporting the suggestion, said that the condition of things which prevailed at present was absolutely absurd—it was impossible to use any other word. If a buyer ordered some butter and was supplied with a mixture contain-

ing margarine, under the Food and Drugs Act a remedy was at once given to the purchaser; but manufacturers and dealers palmed off at the present time *pot-pourris* of metals and alloys on the buyer without any attempt at definition. It was high time the Institute took the matter in hand. As an illustration, only a few months ago he received a sample of brass for report which contained nearly all the common metals in alloy. To designate it "Brass" was an absurdity. It was a compounded alloy. As between buyer and seller, it ought not to have been termed a brass. He hoped that members would take a real interest in the attempt to amend the nomenclature of alloys as the author and others had suggested.

Sir GERARD MUNTZ, Bart., Past-President, said the question was not a scientific, but a commercial one, but he was only too pleased that science should take it up. Mr. Seaton had mentioned an experience of his with regard to manganese bronze. What Mr. Seaton's friend sold him as manganese bronze was no more manganese bronze than morocco leather on a chair—it was manganese bronze brass. As a manufacturer he received specifications asking for various things to be made in gun-metal which it was practically impossible to supply, because it was an extremely difficult metal to work with under certain conditions. Gun-metal could not be handled like ordinary bronze metals. What the buyer wanted was really not gun-metal at all; it was naval brass or something of that nature, but because it had a little tin in it they called it gun-metal. That was a case in point which required close investigation. He wished also to refer to the question of brass. Specifications were sent in to his firm saying that so and so was to be made in brass. What brass?— α brass or β brass, or what? They asked the purchaser what sort of brass he required, and he did not know or care. All he replied was, "I want brass." That was enough for him. The committee would have plenty of scope for a definition of brass only, because there were several mixtures. That state of affairs ran through the whole of the non-ferrous trades to an alarming extent. Looking at the question from a commercial point of view, he would be only too glad to assist the Institute, in any way in the direction of fixing definitely the nomenclature for any particular alloy.

Mr. F. JOHNSON, M.Sc. (Swansea), reminded the author that reference was made to the subject under discussion by a Mr. Rogers at a meeting of the Birmingham Metallurgical Society held some years ago, in which several of the suggestions made by Dr. Rosenhain were put forward. He thought that that paper* might be referred to with advantage. At the same time he thought it would be very hard to live down such old-established terms as German silver and aluminium bronze. The same need existed for standardising terms in relation to copper. Copper alone existed in many varieties on the market, and its nomenclature was greatly in need of standardising.

* *Proceedings of the Birmingham Metallurgical Society, 1908-9.*

The CHAIRMAN said the general feeling of the meeting seemed to be that the subject was worthy of consideration. It was no use, however, to disguise the fact that it was an exceedingly difficult thing to deal with—in fact so difficult that he was afraid the Institute would never get through with it. But he was sure they were quite willing to have a try, and in any case it would clear the ground. Those who looked into the question would soon realise what the real difficulties were. In the case of steel, for instance, it must be borne in mind, that at the present time the altogether inaccurate term “mild steel” was still being used. “Mild steel” was not mild steel. The Germans called it “ingot iron,” which was quite a correct term. It was simply malleable iron which had been molten. An endeavour was made to introduce the term “ingot iron” into this country some years ago, but it was not a bit of good, nobody took any notice of it and nobody ever would. It would go on being called “mild steel” to the end of time. That illustrated the difficulty that had to be contended with in dealing with the nomenclature of alloys. Old-established names could not be swept aside very easily, and everybody, he was sure, realised that the subject bristled with difficulty. He would, however, report to the Council what the views of the meeting were, and he had no doubt that the Council would give them every consideration. The author was satisfied to leave the matter in that way.

COMMUNICATIONS

Mr. G. ALMOND (Horwich) wrote that he was glad to see that at last a suggestion has been put forward for the introduction of a proper nomenclature of commercial alloys. That such a nomenclature was required was beyond all doubt, for one had only to look around to find that confusion was the order of the day, and that, when a man spoke of brass or bronze, one was apt to ask the question, do you mean a copper-tin or a copper-zinc alloy? So far have the names or terms of commercial alloys been twisted. In fact it was not an uncommon thing to find that some of the engineers connected with some of our largest engineering firms fell into the error of using the single term brass to mean quite an array of copper-tin as well as copper-zinc alloys. Further, the practice seemed to be growing in some directions, for many of our young engineers were following this example, and were falling into the error of calling everything they touched containing copper, and having a yellowish look, brass. He agrees with the author that much revision was needed, and proper terms arrived at, for use in connection with such alloys as copper-aluminium and copper-nickel. The author suggests that such alloys as “aich metal” be termed “iron brass,” and brasses containing large proportions of lead “lead brasses.” He would raise the point, however, as to what was meant by “large proportions” of lead; would it be understood to apply to alloys containing 1·0 per cent. lead and upwards, or would it apply to brasses containing even lower percentages than that?

—for of course a minimum should be placed, which might be based with advantage, on the least amount of metal which definitely affected the working properties of the alloy of which it was a constituent.

The author was quite right in mentioning that trade names, which were intended to convey to the purchaser an idea of the character and composition of an alloy, were often misleading, so much so that many manufacturers ordered an alloy of the type they thought suitable for their requirements, only to find that the name was one thing and the alloy quite another.

In the laboratory also such a nomenclature would be welcomed, if only in order to simplify methods of recording analysis. He therefore agreed with the author that it would be a good thing if the Institute appointed a strong committee, consisting of both the technical and scientific side of the members, to consider this matter, and ultimately to present to the Institute a list of terms that could be looked upon as correct.

Dr. C. H. DESCH (Glasgow) wrote that he was in general agreement with the author's suggestions, especially in regard to the misuse of the term "bronze." The specific changes proposed were in the right direction, but would not, of course, cover the whole ground. It was to be hoped that the matter would be referred to a representative committee, which could survey the question of the nomenclature of alloys as a whole and could, after arriving at some preliminary conclusion, enter into communication with the International Association for Testing Materials. If the matter were to be studied thoroughly, it would be well to include the further question of the scientific nomenclature of the constituents of alloys. Thus Kurnakoff had introduced the plan of designating inter-metallic compounds containing tin or mercury as stannides or mercurides, &c., but the proposal had not been generally adopted. With the advance of metallography, names of some kind would probably become necessary, and it was undesirable that the confusion in the nomenclature of constituents of iron and steel should be repeated in the case of alloys in general.

Mr. W. N. STANLEY (London) wrote that while endorsing Dr. Rosenhain's proposal for a committee of inquiry on the nomenclature of alloys, he failed to see why it should be confined to the alloys of copper only. He considered that the committee should be placed on a permanent basis to deal with the question of non-ferrous alloys generally. While agreeing with Dr. Rosenhain that the names of some alloys were certainly obvious inconsistencies, he was afraid that any attempt to rectify them would only add to the confusion. It might be easy for a committee to say that in future "Electrum" was to be called "Nickel Brass," but to get the trade to adopt the committee's ruling would be quite another matter, and the interference might be resented. But there was no need for that to deter the committee, should it be appointed, as there was plenty of work to be done. It was a well-known fact that there were hundreds of alloys in existence, and there were also

dozens of books on the subject, but it was not an easy matter to find information on an obscure alloy. Therefore why should not the proposed committee get to work with the intention of producing a standard index of alloys giving all the available information as to nomenclature, composition, physical properties, and practical uses of all the known alloys, and when such an index had been issued, an appendix could be issued from time to time giving all the latest data obtainable. That would bring the Institute forward in the eyes of the trade generally, who would no doubt give the proposed committee all the assistance required.

Mr. F. TOMLINSON (Manchester) wrote that he wished to express his appreciation of the author's short paper, as he (Mr. Tomlinson) had often felt that there was an urgent necessity for some simple indicative nomenclature of alloys. In the brass and copper trade the misuse of the terms brass and bronze, &c., was of only too frequent occurrence.

In such system of nomenclature it was important that class names, such as brass or bronze, &c., should if possible be retained for each particular group of alloys, and such class name might be employed in conjunction with a simple formula indicating the approximate composition of the particular alloy.

Mr. H. J. YOUNG (Wallsend-on-Tyne) wrote that his experience showed that users of alloys would leave compositions as a matter for the makers, their properties being all that concerned the user—hence, commercially speaking, the name of an alloy must be that which would imply for what purpose it was suitable.

For instance, taking certain districts and trades, it would be found that yellow metal or yellow brass might be anything from Muntz metal to an alloy of the composition of Admiralty condenser tubes, including all the low-percentage complex alloys which makers had neglected to misname bronze.

Speaking from a scientific standpoint, he agreed with the author's suggestion, but from a commercial point of view he had strong convictions that the best scheme would fail, for the following reasons:—

1. A "coined" name sold an alloy better than a scientific formula (or part of one).

2. A name expressing composition would to most users be like Greek to one who had not learned it.

3. Producers would fight shy and blame the Institute for interfering with things which, to their minds, did not need altering.

4. Users would find it complicated to explain in their specifications and to their customers.

5. If the commercial world rearranged its nomenclature of alloys, it would not be to the liking of science, and *vice versa*.

6. The many makers of "manganese bronze" containing very little manganese, or of "bronze" consisting essentially of copper and zinc, were nearly always scientific firms and had deliberately named their

alloys. The bald statement that both "brass" and "bronze" were recognised trade terms and had nothing to do with their dictionary meanings, and that the trade was full of such examples, should be enough to show the futility of scientific classification.

Dr. ROSENHAIN wrote, in reply, that he was very pleased to find that his proposal for taking steps to effect an improvement in the nomenclature of alloys had met with support from so many important members. The difficulties which had been pointed out in connection with his own tentative suggestions for nomenclature were only a few of those which were bound to be encountered by any such scheme, and as he had fully recognised that difficulty, he had merely put his suggestions forward as a basis for discussion; the whole question was so large and so difficult, that it would require a representative committee—representative of the industrial and commercial side as well as of the scientific—to deal with it adequately. Of course even such a committee would possess no legislative powers and could not enforce the use of the nomenclature which they proposed, but if their proposals were sound and satisfactory he ventured to think that they would gradually find their way into practically universal use—their nomenclature might even acquire legal importance. Mr. H. J. Young's remarks were, he thought, perhaps influenced by a slight misunderstanding of the author's ideas and proposals. It was not in any sense a question of "science" re-arranging the terms used by the commercial world, but of a re-arrangement arrived at, or rather to be arrived at in the future, between the "commercial world," "science," and the technical users of alloys, with the sole object of benefiting all concerned. It would be a deplorable mistake to introduce any question of antagonism between these classes in such a matter. Further, he (Dr. Rosenhain) had been careful to refer to that very point of "coined names"; where "coined names" were frankly used as such, no one could reasonably object to them except perhaps the consumers, who might well ask for a name which had some definite meaning—the more important consumers of alloys were very well able to understand the compositions of alloys. On the other hand, if the firms who misused such definite terms as "bronze" and "manganese bronze" were really scientific, as suggested by Mr. Young, then in this particular respect they had acted in a way which was not only un-scientific, but was really unwise from every point of view, since it had led to confusion and misunderstanding. The existing confusion of terms, so far from showing the futility of scientific classification, clearly demonstrated the need for some systematic re-arrangement.

THE INFLUENCE OF TIN AND LEAD ON THE MICROSTRUCTURE OF BRASS.*

BY F. JOHNSON, M.Sc. (SWANSEA).

WITH a view to elucidating the exact relations which exist between tin and lead when occurring together in brass, the author recently made a series of experiments, which are herein described.

The statement made by Professor Louis in a paper† read by him at the 1911 Autumn Meeting of the Institute was challenged by the author in his contribution to the discussion.

The statement, which referred to the reticulated structure caused by the presence of lead and tin in a brazed joint, was as follows:—"I have therefore no doubt but that this appearance was caused by an alloy consisting essentially of lead and tin, much more fusible than brass, which solidifies about the crystals of brass; the planes thus formed constitute planes of weakness, liable to yield under strain, and thus allowing liquids to penetrate into the mass of the metal." Experimental alloys were made by Professor Louis, with the object of imitating the composition and structure of the braze.

Since those alloys were not analysed, however, it cannot be said that they exactly corresponded to the braze in composition, but it is quite probable that, owing to the inevitable loss of some zinc when making brass alloys, the analyses would approximate fairly closely, for the ratio of zinc to copper used in preparing the experimental alloys was higher (viz. 33·3 to 66·6) than that in the braze (31·3 to 66·6).

The structure of the braze was imitated, however, with a definite degree of success, the "reticulations" being faithfully reproduced.

* Read at Annual General Meeting, London, January 17, 1912.

† "Failure of a Brazed Joint," Professor H. Louis, *Journal of the Institute of Metals*, No. 2, 1911, vol. vi, p. 224.

INFLUENCE OF TIN.

So far as the author has been able to judge from his experience with commercial brass alloys, it has seemed to him that tin could exist in solid solution in brasses consisting wholly of the α phase, after the processes of cold-drawing and annealing, to the extent of at least 1 per cent.; also to the same extent at least in alloys consisting of the α and β phases, in the cast or rolled condition.

In order to confirm this, the author made alloys of the following composition:—

	Alloy I.	Alloy II. (Naval Brass.)
	Grammes.	Grammes.
Copper . .	70.0	62.0
Zinc . .	29.25	37.0
Tin . .	0.75	1.0

Electrolytically-deposited copper, the purest stick zinc, and Straits tin were used.

The copper was melted under a layer of charcoal in a covered clay crucible, the zinc and tin added, the mixture well stirred with a charred stick, and allowed to cool under charcoal in the crucible.

MICROSCOPICAL EXAMINATION.

When quite cold, microsections were sawn from each alloy, ground on an emery-wheel, polished on graded emery-papers, and finally with Globe polish on chamois leather. The surface was etched with a dilute solution of ammonium persulphate. In alloy I. (see Plate XVIII. Fig. 1) there were numerous areas similar in structure and colour to the $\alpha + \delta$ eutectoid appearing in gun-metal (*c.g.* 88 per cent. copper, 12 per cent. tin), an excellent illustration of which is shown in Law's "Alloys," photomicrograph No. 11. The difference from the latter lies in the fact that the eutectoid in a brass consists

probably of the α phase (solid solution of zinc in copper) plus SnCu_4 (appearing white in photomicrograph), while that in a bronze consists of the copper-tin α phase plus SnCu_4 .

Alloy II. (naval brass) showed none of these areas, the typical structure caused by the presence of the α and β phases together being revealed. As will be seen from Plate XVIII. Fig. 2, there are just traces of thin pale blue films of SnCu_4 separating the two phases; there are two small patches also visible in one of the β areas, sufficient time apparently not having been allowed for its complete solution. These passed entirely into solution after annealing at 800°C .

The results of these experiments point to the very slight solubility of tin in the α phase as cast, and to its almost complete solubility in the β phase.

In order to test the effect of mechanical work and annealing on the solubility in the α phase, a piece of alloy I. was rolled cold from $\frac{1}{2}$ inch to $\frac{3}{16}$ inch thickness, and annealed for half-an-hour at 800°C ., and cooled slowly. After polishing and etching, it was seen that very little of the SnCu_4 constituent was visible, most of it having passed by diffusion into the α crystals. In commercial alloys of 70 29 1 composition, it is quite probable that practically all of the tin is thus made to pass into solution by annealing subsequent to rolling or drawing. The author would strongly advocate thorough annealing at a red heat of these alloys at every stage, in order to procure homogeneity of composition, as well as maximum softness for subsequent mechanical "work."

INFLUENCE OF LEAD.

Several workers have shown that it exists in the free state in brass. polished sections of the latter showing black spots and inter-crystalline areas. Bengough and Hudson* have very clearly pointed out the nature of its occurrence in 70 30 brass in the following words:—"The presence of lead is indicated in more or less rounded particles scattered through the crystals." Law,† amongst others, has shown that lead

* "The Heat-treatment of Brass," Bengough and Hudson, *Journal of the Institute of Metals*, No. 2, 1910, vol. iv.

† "Alloys," p. 120.

exists in a similar condition in bronze. The blackness of these areas is probably due to the excessive softness of the particles of lead, which are rubbed away to a greater extent during the polishing than the harder crystals of brass, thus leaving microscopical pits, from which the light from the illuminator of the microscope is not suitably reflected.

INFLUENCE OF LEAD AND TIN TOGETHER.

In order to clear up the point as to the nature of the "reticulations" which Professor Louis believes to be "an alloy consisting essentially of lead and tin," alloys were prepared corresponding to Professor Louis's alloys A, B, and D.

They were prepared in exactly the same way as alloys I. and II., and were constituted as follows:—

	Alloy III. (Pure Brass.)	Alloy IV.	Alloy V.
	Grammes.	Grammes.	Grammes.
Copper	66·66	66·66	66·66
Zinc	33·33	33·33	33·33
Tin . . . .	...	0·75	0·75
Lead . . . .	...	...	0·5

The alloys were analysed, and were found to have the following composition:—

Analyses.

	Alloy III.	Alloy IV.	Alloy V.
	Grammes.	Grammes.	Grammes.
Copper	67·46	66·96	66·54
Zinc (by difference)	32·54	32·32	32·14
Tin	Nil	0·72	0·78
Lead	Nil	Nil	0·54

It will be seen from these figures that, although the copper was not exposed for a moment to the oxidising action of the

air, either previous to or during the introduction of the zinc, there was a loss of the latter metal (due to volatilisation) representing about 1.1 per cent. of the total alloy in each case.

It is not clear from Professor Louis's description whether he added the impurities in the above way, or whether he substituted them for equivalent weights of copper or zinc. The difference would be of little importance if he did take the latter course, so that the above alloys III., IV., and V. may be taken to correspond respectively to Professor Louis's alloys A, B, and D.

It will be noticed that the ratio of copper to zinc (2:1) is constant throughout. According to the equilibrium diagram (p. 206), this alloy (No. III.) should, under sufficiently slow cooling, consist entirely of the α phase. In ordinarily cooling such an alloy however, and even with the retarded rate of cooling adopted by the author, a true state of equilibrium is not attained, and some of the β phase remains undissolved (see Plate XVIII. Fig. 3). This phase, although stable at a high temperature, is unstable at normal temperature.

It will be noticed that the patches of β are, like the α phase, *structureless*.

In alloy IV. similar patches of β occur, but they are no longer structureless. The pale blue compound SnCu_4 is clearly seen in bunches of grains, and as a film of beautifully uniform thickness enveloping this constituent. The author assumed this to be the result of decomposition of a solid solution of SnCu_4 in the β phase, having proved its comparative insolubility under similar conditions in the α phase (Plate XVIII. Fig. 1), and its solubility in the β phase (Plate XVIII. Fig. 2).

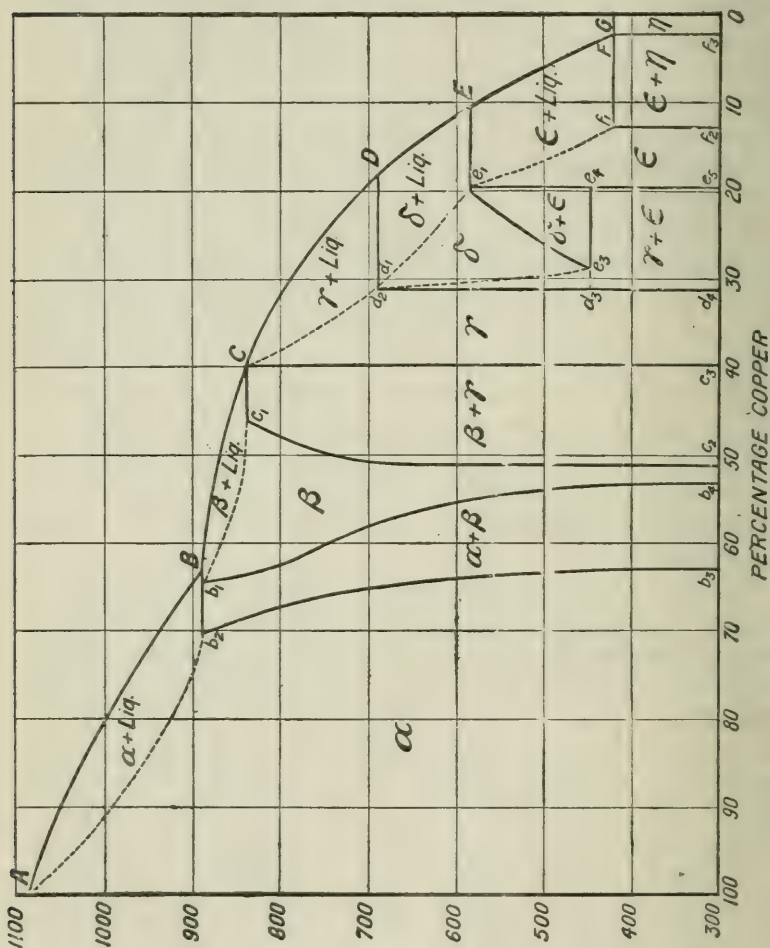
If this assumption were correct, a specimen of the alloy quenched at 800°C . should show no free SnCu_4 , on account of the greater volume of β which exists at that temperature (*cf.* Shepherd's diagram).

Plate XIX. Fig. 4Q shows this to be the case. The specimen was kept at 850°C . for half-an-hour, and then quenched from about 800°C . in cold water.

The duplex character of the β constituent in this case can be explained by assuming that it represents a stage in the

transition of β to α where the two phases exist in intimate mixture. In such a case the tin is probably in solid solution in the β particles.

Since a piece of the pure brass alloy (III.) showed no such



Shepherd's Diagram.

duplex structure when submitted to the same treatment, the author was not inclined to favour the above theory.* What-

* The author has since discovered that the minutely duplex structure of the β phase, when quenched is characteristic of that phase in alloys from 63 to 60 per cent. of copper at least, whether small quantities of tin are present or not.

ever the theory may be, the separation of SnCu_4 as "reticulations" can be safely ascribed to insufficiency of the β constituent to hold it in solid solution.

Incidentally, it will be noticed that the β constituent occupies a greater area in the quenched than in the slowly cooled specimen (compare Plate XIX. Fig. 4Q and Plate XVIII. Fig. 4). This is only what one would expect from a study of Shepherd's diagram.

Plate XIX. Fig. 5 shows the appearance of alloy V. under low power.

The presence of free lead as globules and inter-crystalline areas is shown by the black spots; these are not present in alloys III. and IV., which contain no lead. The "reticulations" which appear as faint light-coloured meshes (specimen unetched) are due to SnCu_4 -bearing β areas, and these have exactly the same structure as that shown in Plate XVIII. Fig. 4 when viewed under high power. Plate XIX. Fig. 6 shows this alloy under higher power and after etching. The black particles of lead are seen clearly having a separate identity from the "reticulations."

CONCLUSIONS.

1. Tin is only slightly soluble in the α phase of the degree of concentration existing in "70/30" alloys as cast. Rolling and annealing help it to pass into solution.

2. Tin is readily soluble in the β phase (limit undetermined) as contained in alloys of the naval brass type, even in the cast condition.

3. The "reticulations" caused by the presence of tin in a brass in which the ratio of copper to zinc is 2:1 have no structural relations with any lead which may be present, the latter existing in the "free" state. This is probably true of all α brasses.

4. The "reticulations" are due to the deposition of SnCu_4 from the metastable β constituent, which is insufficient in quantity to retain it in solid solution.

Finally, the author would point out how the foregoing experiments explain why it is advisable in works' practice:

(a) Thoroughly to anneal castings of the 70, 29/1 and the 62 37/1 (naval brass) compositions *before* subjecting them to mechanical treatment, in order that the brittle tin compound may pass into solution; (b) to allow material made of naval brass to cool slowly after annealing for the same reason.

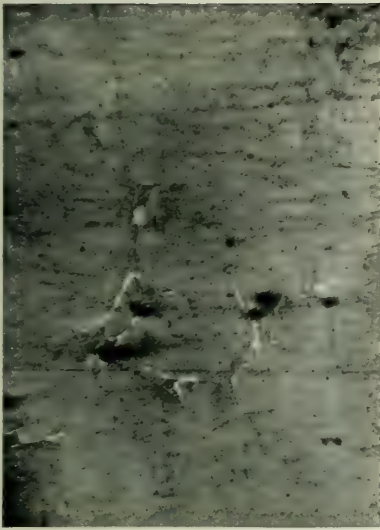


FIG. 1.—Alloy I.

"70 30" Brass, containing 0.75 per cent. tin. Showing insolubility of SnCu_4 in the α phase. Magnified 180 diameters. Vertical illumination. Etched.

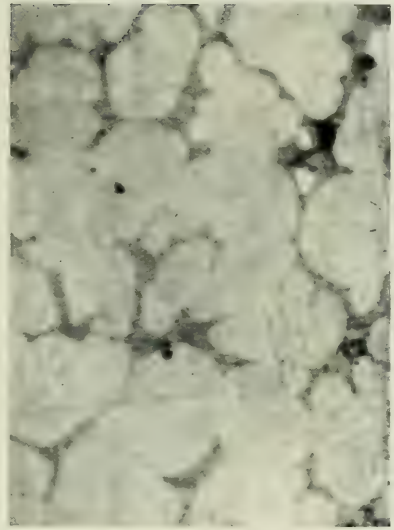


FIG. 2.—Alloy II.

Naval Brass, slowly cooled. Showing solubility of SnCu_4 in the β phase. Magnified 180 diameters. Vertical illumination. Etched.



FIG. 3.—Alloy III.

Pure Brass, slowly cooled. 2 copper to 1 zinc. Shows areas of β . Magnified 180 diameters. Vertical illumination. Etched.



FIG. 4.—Alloy IV.

Same as alloy III., but containing tin. Shows separation of SnCu_4 constituent from the β phase. Magnified 180 diameters. Vertical illumination. Etched.

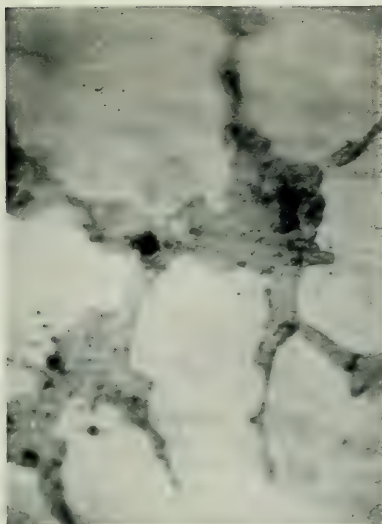


FIG. 4Q.—Alloy IV.
Showing effect of quenching at 800° C. brass
containing the tin-bearing β phase. Mag-
nified 180 diameters. Etched.

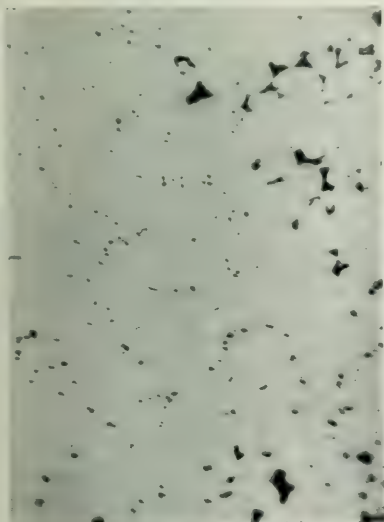


FIG. 5.—Alloy V.

Showing existence of lead (black spots) inde-
pendently of the SnCu_4 areas in brass.
Magnified 40 diameters. Unetched.

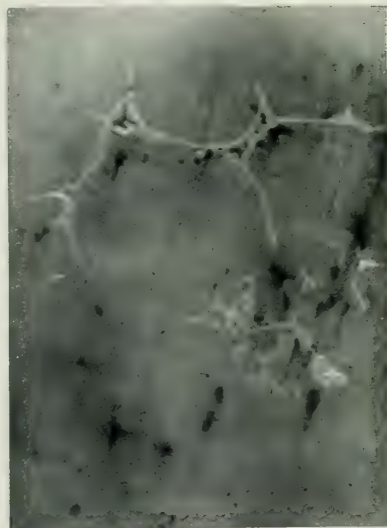


FIG. 6.—Alloy V.

Same as Fig. 5, under higher magnification.
Magnified 180 diameters. Vertical illu-
mination. Etched.

DISCUSSION.

The CHAIRMAN said the author had based his paper on a paper read at a previous meeting, a course which was not usually adopted. The author was not present at the previous meeting at Newcastle, and had not heard the discussion that took place there, otherwise perhaps he might not have written the paper. He had elaborated the subject much more fully than the discussion at Newcastle had, and from that point of view it was perhaps fortunate that he had not seen the print of the discussion that then took place. He (the Chairman) criticised Professor Louis's paper at the Newcastle meeting, and took the same view of the matter that Mr. Johnson now took, and in the proceedings a microphotograph was incorporated which very closely resembled those that the author had just thrown on the screen. On that account he did not think it was a matter of regret that the paper had been written, in order that the subject might be further discussed.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), said the author had stated in his paper that he hoped the brasses would be heat treated in the manner described in the paper. He wished to observe that he knew of not only one but three or four firms where the operation had been carried out for some years. The subject, however, had not been brought forward to the extent that it deserved. His main reason for making those observations was to point out that "non-ferrous practitioners" who attended the meetings of the Institute, some of whom were members, were really carrying out the author's suggestion, although they did not publish the fact. Further, the cost of the preliminary heat treatment was often urged against its conduct. Such had been the case in all instances where he had recommended such departures.

Mr. F. JOHNSON, in reply, said that the works' practice referred to by Mr. Vaughan Hughes was of course very well known, and the annealing mentioned in the paper was carried out by various firms. Some firms probably had not observed the necessity for the *thorough* annealing which he advocated, but the object of the paper was more to explain why it was necessary to anneal rather than to advise.

COMMUNICATIONS.

Mr. G. ALMOND (Horwich) wrote that the author's remarks with regard to the conclusions of Professor Louis as to the cause of failure of the brazed joint were very interesting, and he (Mr. Almond) could amplify them.

He was rather surprised at the conclusion arrived at by Professor Louis as to the initial cause of the failure being due to an alloy consisting essentially of lead and tin, because he had always understood it to be a

well-known fact that lead existed in the free state in brasses of the nature treated; but whilst the presence of tin did not affect the lead constituent in any way, it alloyed with the copper to form SnCu_4 , which, as the author clearly showed, was only very slightly soluble in the α phase of the 70-30 alloys, but completely soluble in the β phase.

The above statement, made by Professor Louis *re* the tin-lead alloy, turned his (Mr. Almond's) mind in a similar direction to that of the author, and from experiments, made on similar lines, he could agree in almost every particular with the conclusions arrived at by Mr. Johnson.

That the reticulations seen in the brazed joint did play a part in the failure there could be no doubt, because the SnCu_4 constituent (for he believed the reticulations to be entirely due to the segregation or deposition of the above constituent during the cooling down of the mass) in the free state, as seen in the α phase, was brittle, and so it created planes of weakness, and these would no doubt yield (as Professor Louis suggested) under strain, and in this way play the initial part towards the complete failure of the braze.

He was glad to see the plea put forward by Mr. Johnson for more attention to be paid to the question of annealing. That was often put into the background by many of our manufacturers to the detriment of their customers, who have often to stand the cost of failures, occurring because of insufficient annealing or other suitable heat treatment; but from the clear and brief way in which Mr. Johnson put forward the advantages to be derived from suitable annealing, coupled with the results of other investigations carried out by prominent members of the Institute, manufacturers would, in the near future, have no excuse as to not knowing the right course to adopt in this matter.

Mr. G. E. BUTTENSHAW (Chorlton-cum-Hardy) wrote, with reference to the statement (on page 203) that "the results of these experiments point to the very slight solubility of tin in the α phase as cast, and to its almost complete solubility in the β phase," this deduction seemed to lack conclusive proof, and to be contradicted by the author's micrograph, Fig. 4, Plate XVIII., which drew attention to the separation of SnCu_4 constituent from the β phase. Also the final conclusion that castings of naval brass should be thoroughly annealed "in order that the brittle tin compound may pass into solution," (*b*) "to allow material made of naval brass to cool slowly after annealing for the same reason," seemed to the writer doubtful, unless after annealing quenching were resorted to.

The writer had had occasion to examine the behaviour of tin under certain conditions in alloys (known as high-strength brass) of the following composition:—

	Per Cent.
Copper	56.60
Zinc	39.90
Iron	1.45
Manganese	0.80
Tin	1.00
Aluminium	0.25

In alloys of the above composition the basis was a copper-zinc alloy producing the characteristic $\alpha + \beta$ phase of brass containing 60 per cent

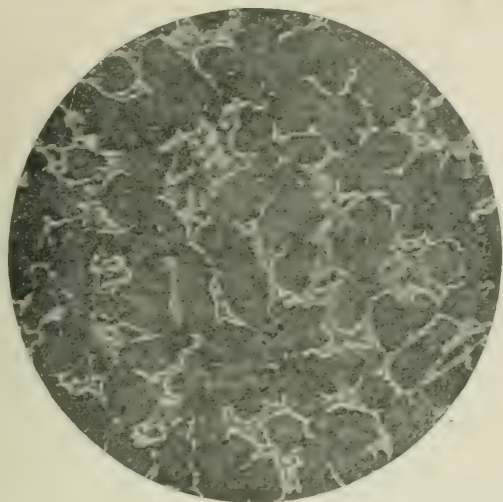


FIG. 1.—Annealed. Slowly cooled. Magnified 70 diameters.

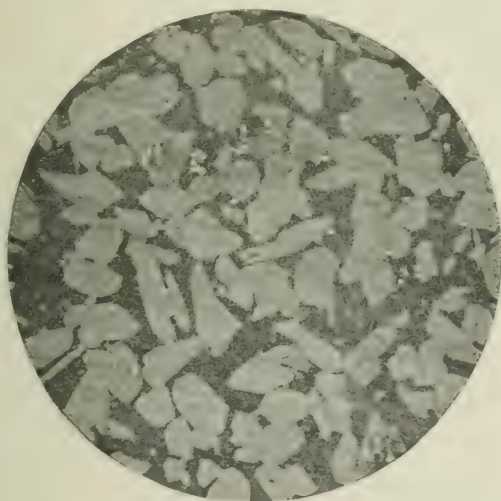


FIG. 2.—As cast. Magnified 100 diameters.

copper, 40 per cent. zinc, and relatively more of the β phase than in those samples experimented upon by Mr. Johnson.

While the additional elements iron, manganese, and aluminium might, and probably did, play an important part in the different behaviour of

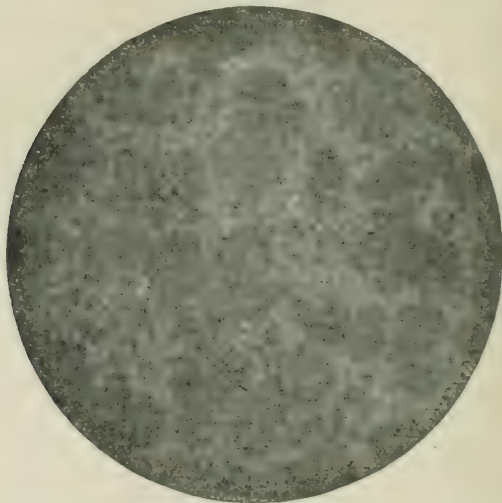


FIG. 3.—Cast. 1 per cent. Tin. Magnified 100 diameters.

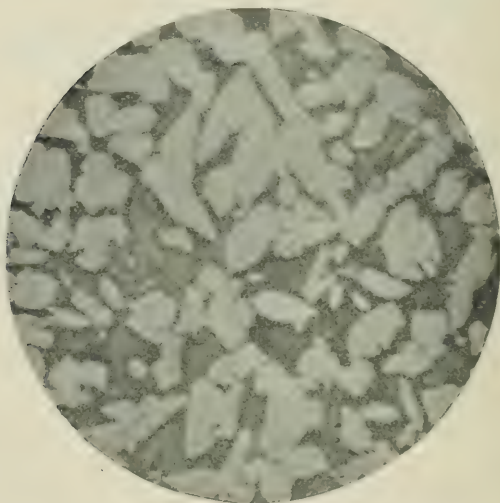


FIG. 4.—Normal as cast. 1 per cent. Tin. Magnified 100 diameters.

tin in that alloy, still some illustration of the effects noted might be of interest, and have some bearing on the problem. The conclusions of the

writer were that tin was to a certain extent soluble in the α phase, but that when lead was present in quite small proportions an alloy, consisting essentially of tin and lead, liquated out, and that such liquation was aggravated by annealing and slow cooling. That might be seen to have taken place in microphotograph Fig. 1, which was that of an alloy as described above, but containing 1.57 per cent. tin, 0.37 per cent. lead, the zinc content being 40.13 per cent., which had been annealed at 750° C., and slowly cooled. Fig. 2 illustrated a sample containing 1 per cent. tin and about the same amount of lead as cast. A further curious effect was noted, and was illustrated by Fig. 3 with 1 per cent. tin, that if the alloy was allowed to become badly oxidised in melting, a similar liquation took place, as in Fig. 1, on casting, although in that case lead was only present in very small quantity (about 0.17 per cent.).

That tin was to some extent soluble in the α phase, might perhaps be indicated by the fact that 1 per cent. tin conferred a higher yield point on those alloys when making tensile tests; therefore, as the α phase was much the more ductile constituent of the $\alpha + \beta$ composition, it would appear evident that the α phase had been stiffened by the addition of tin, provided always that no liquation had taken place, and a normal structure, as in Fig. 4, was obtained.

The appearance of the author's microphotographs, Figs. 1, 4, and 6, seemed to suggest that there had been liquation from the α crystals, but there did not appear to be any evidence of solubility in the β phase.

In order to form some idea of the nature of that liquating constituent, the writer scratched the surface of the specimen with a hard steel needle, and noticed that an examination by still higher powers showed those areas to be soft and plastic, which one would hardly expect to be the case if the compound were SnCu_4 . In conclusion, the writer thought that Professor Louis was probably correct as to the cause of the defective braze referred to at the commencement of Mr. Johnson's paper, and would further suggest that probably similar defects might be set up in brazed joints when tin was present, if inadvertently an oxidising flame were brought to play on the melting alloy, even though no lead, or only traces, might be present.

Mr. R. M. SHEPPARD (Birmingham) wrote that he did not entirely agree with the author's final conclusion that material made of naval brass should be allowed to cool slowly after annealing, in order that the brittle tin compound might pass into solution.

From that conclusion it appeared that naval brass that had been quenched in water after annealing must be more brittle than naval brass that had been slowly cooled.

Theoretically, Mr. Johnson might be perfectly right; but practically, he thought, he was certainly wrong, as, in a number of experiments made by him (Mr. Sheppard), better mechanical results were always obtained with samples of brass that had been quenched. The following table would illustrate that:—

Naval Brass Bars Hot Rolled and Finished Cold Rolled.	Annealing Temperature, °C.	Time (Minutes).	Cooling.	Tensile Strength. Tons per Sq. Inch.	Elongation on 2 Inches. Per Cent.
1	450	30	Quenched	29.18	20
2	475	30	"	28.74	31
3	500	30	"	27.70	47
4	550	30	Slowly	27.86	31
4-A	550	30	Quenched	28.40	36
5	600	30	Slowly	24.02	39
5-A	600	30	Quenched	24.44	57
6	700	30	Slowly	25.10	41
6-A	700	30	Quenched	25.56	51

He (Mr. Sheppard) was not prepared to state that it was always an advantage to quench naval brass after annealing, for it must naturally depend on several considerations, such as the mechanical requirements, the form in which the metal might be used, &c. Also, he did not recommend quenching naval brass from a temperature below 500° C., as it was liable to fracture at that temperature if subjected to shock of any description.

With Mr. Johnson's other conclusion he was in entire agreement, namely, that castings of the 70:29:1 and the naval brass compositions should be thoroughly annealed before being subjected to mechanical treatment.

Mr. JOHNSON wrote in reply to Mr. Almond's contribution that he fully appreciated the remarks made, particularly as they were supported by personal experiment, and he was much pleased to learn that Mr. Almond's conclusions coincided with his own.

With reference to the action of free SnCu_4 in a brazed joint, the author had indicated that action when introducing his paper at the meeting, pointing out the brittleness of the constituent, and the readiness with which it fell out from its position in the eutectoid during polishing.

During the bending of a copper steam-pipe, especially if the brazed joint were not in the position where it would be subjected to minimum stress, the SnCu_4 particles would have insufficient ductility to accommodate themselves to the stress imposed, and would readily form fissures and pits, which would afford centres for corrosion.

The author thought, therefore, that tin, irrespective of the presence of lead, was dangerous in brazing metal, particularly as he had occasion to believe that, by ordinary annealing, the SnCu_4 constituent in a brazed joint of the composition examined by Professor Louis would not pass into solution.

The author was much interested in Mr. Buttenshaw's remarks and his references to the condition of tin in alloys which he (Mr. Buttenshaw) had examined.

Referring to Plate XVIII. Fig. 4, the author failed to see how that photograph contradicted his conclusion that tin in the proportions mentioned was completely soluble in the β phase, as he had already demonstrated in that particular instance that not only was there insufficient β to hold the SnCu_4 in solid solution, but what β there was, was in an unstable condition. He (the author) had further demonstrated that in an alloy where the β was in stable equilibrium (*e.g.* naval brass) the SnCu_4 was completely soluble in that phase.

Mr. Buttenshaw referred to the fact that the effect of 1 per cent. tin in alloys constituted of α and β in raising the yield point was evidence that some tin had entered into the composition of the α phase. The evidence, however, was incomplete. There were three important things to remember:—

(1) The presence of the other elements—iron, manganese, and aluminium.

(2) The fact that tin altered the relative proportions of α and β in such alloys, hence the increased yield point might be due to the increased proportion of β , particularly as it was stiffened by tin.

(3) The fact that those alloys consisted of the β phase alone when crystallisation occurred, presuming that the presence of the above-mentioned elements did not alter the conditions of equilibrium of the copper-zinc series immediately after solidification. The alloys deposited α at their respective inversion points, and the *indirect* influence of tin on the composition of the α phase must be taken into account. In the tin-free alloy the β phase possibly contained more of the elements mentioned than it did in the alloy containing tin, since the latter possibly displaced them, causing them to concentrate to a greater extent in the α phase, thus giving it the extra stiffening to which Mr. Buttenshaw attributed the increased yield point.

These considerations were merely speculative, but they would show that in complex alloys, what seemed a simple and obvious explanation was not necessarily correct.

Mr. Buttenshaw's adherence to the theory that tin and lead formed an alloy was regrettable, since the author's micrographs showed clearly that free lead separated from the SnCu_4 eutectoid. As that evidence had been further confirmed by Professor Huntington's remarks at the Newcastle meeting, and by Mr. Almond's communication, the author thought it sufficiently convincing. It was, however, true, that the lead particles, although having an entirely separate identity from the SnCu_4 constituent, tended to segregate into the eutectoid areas during annealing.

The very interesting photomicrographs provided by Mr. Buttenshaw in support of his views failed, the author thought, in affording any evidence of the existence of a definite constituent "consisting essentially of lead and tin."

Complete analyses of the alloys represented by the photomicrographs would have helped materially in their interpretation.

Iron, manganese, and aluminium, according to Guillet,* each tended

* L. Guillet, *Revue de Métallurgie*, 1906, iii. 243.

to produce a structure in which the β phase was in relatively greater or less proportion (than the α phase) than in a similar alloy which did not contain them.

What their combined action was in the case of Mr. Buttenshaw's alloys, where lead and tin also occurred, was a problem requiring solution. Therefore the author thought that, interesting as Mr. Buttenshaw's alloys were, they were too complex to afford any direct explanation of the behaviour of tin and lead in brass free from other impurities.

Aluminium, manganese, and iron probably had a great influence on the solubility of tin in the β phase, but it was too early yet to be able to predict that influence either qualitatively or quantitatively.

With regard to Mr. Buttenshaw's unbelief in the existence of the compound SnCu_4 , which he apparently regarded as a soft and plastic lead-tin compound, the author could only repeat that in his experience

- (1) The compound was hard and brittle, not revealing polishing scratches, as did the surrounding brass.
- (2) It was identical in appearance and behaviour with the SnCu_4 of the bronzes.
- (3) It existed alike in a lead-free brass and in a brass containing lead. In the latter case, the lead had an unmistakably separate identity.

Mr. Sheppard's communication was most interesting. The author had anticipated a challenge of his final conclusion, and was glad that that challenge had come from Mr. Sheppard.

Mr. Sheppard's figures were of extreme interest, and were certainly new to the author, and at first sight seemed to stand for a victory of practice over theory.

The results of practice were indisputable, and where they conflicted with theory, the latter required amendment. It was such an amendment that the author felt called upon to make.

It was a well-known fact that quenching Muntz metal above 700°C . greatly impaired its useful properties, and Hudson and Bengough* had attributed the deterioration to the greater proportion of the β phase which existed at the quenching temperature.

A similar structural alteration took place in the case of naval brass, and one would expect a similar reduction in strength, but Mr. Sheppard's results showed that a gain in ductility accompanied quenching above 500°C . That tended to show that a polymorphic change took place in the condition of the β phase in the neighbourhood of 500°C . akin to that which Professor Carpenter had recently demonstrated.† To what extent that change was influenced by the dissolved SnCu_4 , and how it was related, if at all, to the inversion $\beta \rightarrow \alpha + \delta$ which occurred in the copper-tin bronzes, the pyrometer and microscope could alone determine. The theory that some such change did occur seemed to be supported by Mr. Sheppard's statement that there was a critical range of temperature in the neighbourhood of 500°C ., where the naval brass was "liable to fracture . . . if subjected to shock of any description."

* *Journal of the Society of Chemical Industry*, January 31, 1908.

† *Journal of the Institute of Metals*, No. 2, 1911, vol. vi.

It was this "tenderness" which the author also had observed in practice which had induced him to come to the conclusion challenged by Mr. Sheppard, viz. that naval brass should be slowly cooled after annealing. Mr. Sheppard's experiments showed that quenching well above 500° C. was, if anything, beneficial.

It would not be safe, however, to entrust the operation to unskilled workmen, particularly where furnace temperatures were not uniform.

Finally, he (Mr. Johnson) was glad to have had those practical communications, to obtain which had been the main object of the paper. He therefore offered his thanks to Messrs. Almond, Buttenshaw, and Sheppard for their valuable contributions.

THE INFLUENCE OF OXYGEN ON COPPER CONTAINING ARSENIC OR ANTIMONY.*

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WHEN oxygen is introduced into pure copper it exists in the metal as cuprous oxide, Cu_2O , which forms a eutectic with the copper containing 3.45 per cent. Cu_2O , equivalent to 0.39 per cent. of oxygen.† The influence of oxygen on the properties of pure copper was first investigated by Hampe,‡ who found that—

0.45 per cent. Cu_2O § slightly decreases the tenacity, but does not affect the ductility of pure copper;

0.90 per cent. Cu_2O causes some diminution in ductility;

2.25 per cent. Cu_2O considerably lessens the tenacity, and the presence of more renders the metal first cold- and then hot-short.

According to Keller,|| the best pure refined electrolytic copper may contain 0.6 to 0.8 per cent. Cu_2O , while a similar metal with 2 to 3 per cent. Cu_2O may still be rolled into sheets.

All samples of commercial tough-pitch copper contain oxygen in amounts varying approximately from 0.05 to 0.15 per cent. If the metal contains much more than this, or if some is removed, as in overpoled copper, its strength, ductility, and malleability are impaired. The effect of oxygen on tough-pitch copper has been dealt with recently by Mr. F. Johnson.¶ The study of tough-pitch copper, how-

* Read at Annual General Meeting, London, January 17, 1912.

† *Mittheilungen aus der Königlichen Technischen Versuchsanstalt*, 1900, vol. xviii. pp. 315-329; *Zeitschrift für anorganische Chemie*, 1904, vol. xxxix. pp. 11.

‡ *Zeitschrift für das Berg-, Hütten- und Salinenwesen*, 1873 and 1874; *Chemisches Centralblatt*, 1874, pp. 378-382.

§ Cu_2O contains slightly over one-ninth of its weight of oxygen.

|| *The Mineral Industry*, 1899, p. 248.

¶ *Metallurgical and Chemical Engineering*, 1910, p. 574; 1911, p. 397; *Journal of the Institute of Metals*, No. 2, 1910, pp. 163-173.

ever, is complicated by the effect of a number of impurities, especially as little is known of the effect of oxygen on copper with any one of these taken alone. In this connection Hampe* found by the addition of arsenate and antimonate of copper to the molten metal, that the former was distinctly more harmful and the latter less harmful than its reduction product. Thus the presence of 0.55 per cent. of arsenic in the form of arsenate was found to induce cold-shortness, while 0.5 per cent. of antimony in the form of antimonate showed no tendency to cold- or hot-shortness. The influence of oxygen in relation to the failure of arsenical copper has been discussed by Messrs. Bengough and Hill.†

The work described in this paper was begun in conjunction with Mr. A. H. Hiorns, as a continuation of that of Hiorns and Lamb,‡ on the effect of arsenic and antimony on copper.

PREPARATION OF THE MATERIAL.

The alloys used were prepared synthetically from pure electrolytic copper. Oxygen was introduced as cupric oxide, obtained by the ignition of recrystallised copper nitrate; arsenic or antimony was added in the form of a rich alloy with copper. In preparing the alloy of high arsenic content, copper was melted in a fireclay crucible, and metallic arsenic added. After stirring, the metal was poured into a warm mould, allowed to cool slowly, and when cold was powdered in a large iron mortar. Any particles of iron which it contained were removed by means of a magnet: the powder was then carefully mixed and sampled for analysis. The antimony alloy was prepared in a similar way. These rich alloys contained

	Per Cent.		Per Cent.
(a) Copper . . .	67.33	(b) Copper . . .	32.84
Arsenic . . .	32.68	Antimony . . .	67.11

On account of the volatilisation of the oxides of arsenic and antimony, and the uncertain oxidising or reducing atmosphere in contact with the metal, it was difficult to obtain

* *Chemisches Centralblatt*, 1875, p. 381.

† *Journal of the Institute of Metals*, No. 1, 1910, vol. iii. pp. 47-52, and discussion.

‡ *Journal of the Society of Chemical Industry*, 1909, vol. xxviii. pp. 451-455.

the definite compositions intended. Finally the method adopted was to melt about half a pound of copper under lump charcoal in a clay crucible. The charcoal was then skimmed off, the copper stirred with a charred stick, and a weighed quantity of cupric oxide tipped in. This rapidly dissolved, and after a few seconds the rich alloy was added, the metal stirred rapidly with an arc-lamp carbon, left in the furnace until dead melted, and then poured into an open mould.

Methods of Analysis.—Arsenic and antimony were determined by distillation, the former from an acid ferric chloride solution, the latter from a solution of zinc and copper chlorides as described by Gibb.* The distillates after neutralising were titrated in the presence of sodium bicarbonate, with a standard solution of iodine. The method of estimating oxygen is described in the Appendix.

TABLE I.—*Copper with Oxygen and Arsenic.*

No.	Composition.		Relative Hardness.	Cold-rolling Test.	Wire-drawing Test.
	Oxygen, per Cent.	Arsenic, per Cent.			
A 1 . . .	0.05	0.05	8.3	β	...
2 . . .	0.07	0.08	7.7	β	...
3 . . .	0.08	0.19	8.4	$\alpha +$	...
4 . . .	0.08	0.29	8.8	α	...
5 . . .	0.08	0.35	9.5	$\beta +$	...
6 . . .	0.09	0.19	8.5	α	...
7 . . .	0.10	0.12	8.4	$\beta -$	...
B 1 . . .	0.10	0.49	8.5	β	$\beta +$
2 . . .	0.16	0.22	8.9	α	α
3 . . .	0.17	0.40	9.2	α	α
4 . . .	0.29	0.04	10.9	β	γ
5 . . .	0.30	0.06	10.4	β	γ
6 . . .	0.31	0.03	10.5	δ	δ
7 . . .	0.33	0.33	8.8	$\beta +$	γ
8 . . .	0.33	0.43	8.6	β	β
9 . . .	0.35	0.19	9.5	α	γ
10 . . .	0.36	0.51	9.5	$\beta +$	γ
11 . . .	0.60	0.24	11.9	δ	δ
12 . . .	0.62	0.03	12.8	δ	δ
C 1 . . .	0.26	0.05	9.3	$\beta -$	α
2 . . .	0.42	0.43	11.5	β	$\beta -$
3 . . .	0.43	0.23	11.2	β	γ
4 . . .	0.48	0.41	12.3	γ	γ

* *Journal of the Society of Chemical Industry*, 1901, vol. xx. pp. 184-187.

TABLE II.—Copper with Oxygen and Antimony.

No.	Composition.		Relative Hardness.	Cold-rolling Test.	Wire-drawing Test.
	Oxygen, per Cent.	Antimony, per Cent.			
A 1	0·21	0·28	7·7	β	β
2	0·24	0·23	8·1	α	γ
3	0·27	0·14	9·3	α	α
4	0·30	0·38	8·6	β	β
5	0·32	0·04	9·3	δ	γ +
6	0·32	0·18	8·9	β	β
7	0·34	0·22	9·8	γ	γ
8	0·41	0·10	11·5	γ	γ +
9	0·46	0·27	10·0	δ	δ
B 1	0·08	0·14	7·4	β	β
2	0·10	0·41	7·8	α	α
3	0·14	0·24	7·4	α	α

Appearance of the Ingots.—The ingots in general showed a longitudinal depression on the surface, but in some cases were flat. With one exception all the flat ingots of the arsenical series contained from 0·05 to 0·10 per cent. of oxygen, with from 0·08 to 0·30 per cent. of arsenic. Alloys whose content of oxygen or arsenic (or both) exceeded these limits showed a depression. Of the series containing antimony, only one ingot showed a flat surface, namely B 1, containing 0·08 per cent. oxygen and 0·14 per cent. antimony. The depression was very slight in B 2 and 3.

INFLUENCE OF OXYGEN ON THE MECHANICAL CHARACTERISTICS.

Rolling Tests.—From the large ingots, pieces having the approximate dimensions 2·5 inches by 0·6 inch by 0·35 inch were cut for rolling. These were rolled cold down to a thickness of 0·02 inch with the necessary annealings, which were carried out by heating rapidly on a clear coke fire to dull redness and allowing to cool in air. This treatment had no effect on the chemical composition. All the alloys of one series were passed through the rolls in succession and received precisely the same treatment. Even those of different series should yield comparable results, for the conditions of the tests were made as nearly as possible the same.

Judged by behaviour in the rolling test, the metals stand in the following order:—

Arsenic:—

Series A: 3, 4, 6 (all rolled very well), 5, 1, 2, 7 (serrations extended 2 millimetres inwards).

Series B: 3, 2, 9 (very good), 7, 10, 8, 1, 4, 5 (very slight cracks), 11, 6, 12 (badly cracked).

Series C: 2 (incipient cracks), 3, 1, 4.

Antimony:—

Series A: 3, 2 (good), 1, 6, 4, 7, 8, 5, 9 (badly cracked).

Series B: 3, 2 (very good), 1 (slightly cracked).

It is unfortunately impossible to make a quantitative representation of behaviour under the rolling test, but in order to present the results concisely a definite mark has been assigned to each alloy. Thus—

α signifies that the alloy rolled well, and remained perfectly sound at the edges.

β signifies that the alloy rolled well, but showed slight cracks or serrations at the edges.

γ signifies alloys inferior to these, surface cracks also being developed.

δ signifies that the alloy cracked badly.

The results of the test are given in Tables I. and II. To these may be added the following results of a similar test by Hiorns and Lamb:*

Copper-Arsenic Alloys.
0·0 to 0·2 per cent. arsenic, "slightly frayed at the edges."
0·2 to 0·5 per cent. arsenic, edges perfect.

Copper-Antimony Alloys.
0·0 to 0·6 per cent. antimony. "The alloys all showed faint cracks along a plane at right angles to the rolls. The cracks increased as the percentage of antimony increased."

An attempt is made to represent these results graphically in Figs. 1 and 2. The compositions of the alloys are shown in the usual triangular diagram, of which only one corner is used.

As the amount of arsenic increases up to 0·5 per cent. the metal may take up more and more oxygen without suffering deterioration in its capacity for rolling. This quantity of

* *Journal of the Society of Chemical Industry*, 1909, vol. xxviii, pp. 453 and 454.

oxygen rises from about 0.05 per cent. to 0.2 per cent. as the arsenic increases from 0 to 0.2 per cent., then more slowly to about 0.28 per cent. as the arsenic increases to 0.5 per cent.

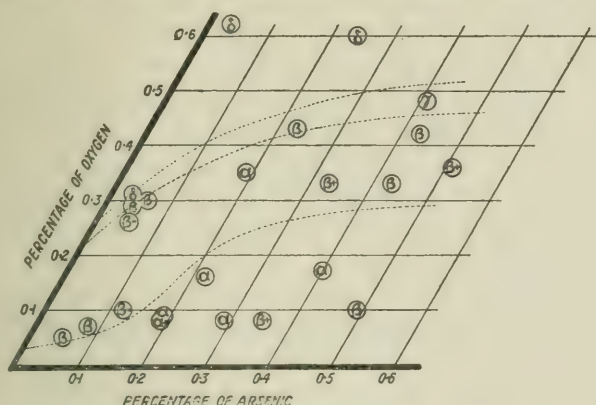


FIG. 1.—Copper with Oxygen and Arsenic. Cold-rolling test.

Thus with constant arsenic, addition of oxygen causes no marked difference to the malleability until a certain limit (depending on the arsenic present) is reached; above this

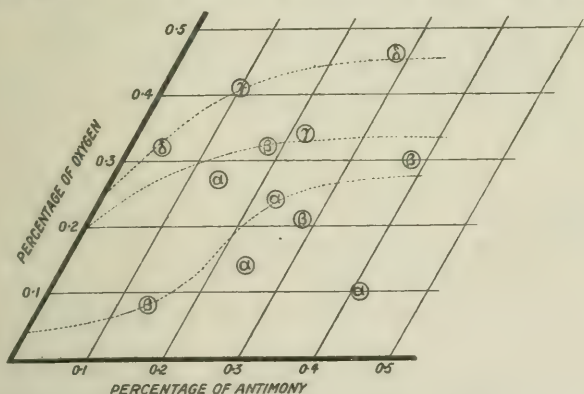


FIG. 2.—Copper with Oxygen and Antimony. Cold-rolling test.

point the malleability falls off, and with still more oxygen there is a rapid deterioration of the metal, which becomes cold-short. If arsenic is increased while the oxygen is kept constant, any tendency to cold-shortness is diminished, and if

less than 0.3 per cent. of oxygen is present, a metal which will roll perfectly is obtained before the arsenic reaches 0.5 per cent.

In a similar way antimony up to 0.4 per cent. reduces the cold-shortness of pure "dry" copper. The first action of oxygen on copper containing a constant amount of antimony, however, appears to be to effect an improvement in the metal, as the cracks mentioned by Hiorns and Lamb in their copper-antimony alloys were not found in the metals B 2 and 3 (containing about 0.1 per cent. of oxygen), which rolled perfectly. Further increase in the oxygen causes a reduction in malleability.

Wire-drawing Tests.—A portion of each ingot was rolled down to 0.15 inch and slit for wire-drawing, which was carried out first on a small draw-bench and afterwards by hand. The results are expressed in Tables I. and II. and in Figures 3 and 4, which are constructed on the same

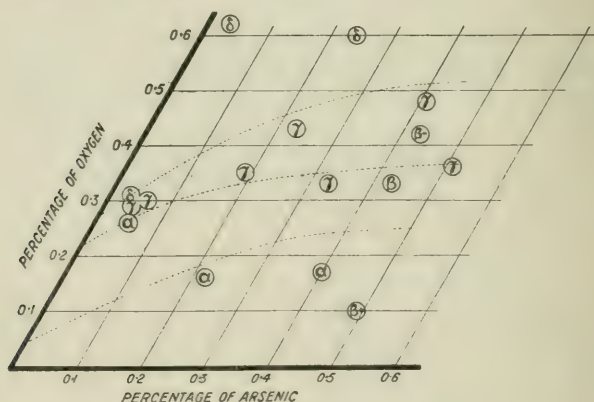


FIG. 3.—Copper with Oxygen and Arsenic. Wire-drawing test.

principle as those for the rolling tests. Alloys marked α and β may be drawn into wire, β — denoting a somewhat rough wire. Those marked γ broke before the 50-hole (diameter 0.033 inch) even with frequent annealing, though a short length of wire was obtained in one or two cases (marked +). Those marked δ would not pass hole 20 (diameter 0.10 inch).

It will be noticed that in the presence of arsenic the compositions of the metals which may be drawn into wire are

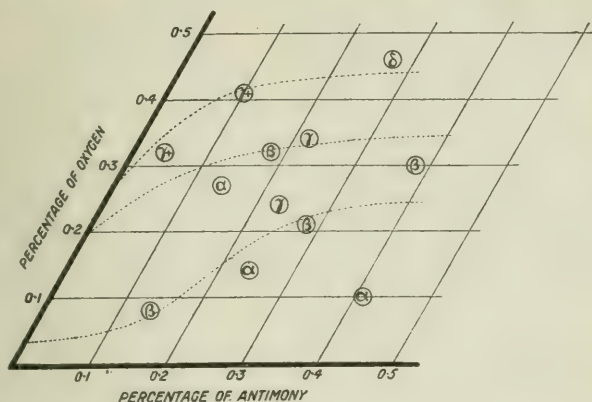


FIG. 4.—Copper with Oxygen and Antimony. Wire-drawing test.

more restricted than for rolling, though in both cases the areas representing their compositions are similar in form.

Tensile Tests.—A number of samples of the cast metals containing arsenic were normalised by heating to about 550°C . in air in a glass tube for $\frac{3}{4}$ hour, and allowing to cool slowly.

The pieces were then planed down to a section of about 0.3 inch square, and broken in a sensitive wire-testing machine. The results are given in the following table:—

TABLE III.

No.	Composition.		Tensile Strength, Tons per Square Inch.			Elongation, per Cent. on 2 Inches.		
	Oxygen, per Cent.	Arsenic, per Cent.	(1)	(2)	Mean.	(1)	(2)	Mean.
B 3	0.17	0.40	11.6	12.3	12.0	28.8	30.0	29.4
C 1	0.26	0.05	9.4	9.4	9.4	14.7	12.0	13.3
B 12	0.62	0.03	...	7.9	7.9	...	2.5	2.5
6	0.31	0.03	7.4	9.1	8.2	5.1	5.1	5.1
4	0.29	0.04	9.8	9.9	9.8	10.0	7.5	8.8
5	0.30	0.06	10.5	10.7	10.6	8.0	9.8	8.9
9	0.35	0.19	9.2	9.3	9.3	11.3	9.8	10.5
7	0.33	0.33	10.7	10.5	10.6	9.6	12.1	10.9
C 3	0.43	0.23	12.4	12.6	12.5	8.2	8.8	8.5
2	0.42	0.43	13.8	13.1	13.5	11.5	10.2	10.9

A further set of alloys was made, and cast in the form of 1 inch diameter bars, about 10 inches long, in a chill mould standing on sand. Each metal was cast as nearly as could be judged at the same temperature. The appearance of the fractures of Nos. 2 and 6 seemed to indicate that the casting temperatures were in these cases slightly higher. The bars were machined down to 0.564 inch diameter, with $2\frac{1}{4}$ inches parallel. Analyses were made on the last turnings from the test-piece. The tests were carried out in the engineering laboratory of this College by kind permission of Professor Elliott. The results are given in Table IV.

TABLE IV.

No.	Composition, per Cent.		Tensile Strength, Tons per Square Inch.		Elongation, per Cent. on 2 Inches.		Fracture.
			Mean.		Mean.		
1	Oxygen, 0.05	Antimony, 0.35	11.09 11.42	11.25	22.5 17.5	20.0	Crystalline: a few small blowholes. Yellowish.
2	„ 0.15	„ 0.38	9.81 9.51	9.66	14.0 13.3	13.6	Fine radiating fibres. Slightly reddish.
3	„ 0.18	„ 0.48	12.63 12.12	12.37	18.5 19.0	18.8	Very finely crystalline to finely fibrous. Slightly reddish.
4	„ 0.31	„ 0.40	10.73	10.73	5.0	5.0	Finely crystal- line. Brick red.
5	„ 0.03	Arsenic, 0.51	11.63 11.28	11.45	29.5 27.0	28.2	Crystalline to silky: a few small holes. Yellowish.
6	„ 0.18	„ 0.33	10.50	10.50	8.5	8.5	Radiating fibres. Slightly reddish.

From the results given in Table III., it appears that for metals in the cast state, containing a constant quantity of oxygen, there is a slight rise in the tensile strength and more marked improvement in the elongation as the arsenic increases. This is seen, for example, in B 6, 4, 5, 9, 7; C 3, 2.

With a constant percentage of arsenic there is very little change in the tensile strength as the oxygen increases from 0.17 per cent. to about 0.4 per cent., but the elongation falls off rapidly. This is evident by comparison of B 3, C 2;

C 1, B 4, 5, 6, 12; and is borne out by Nos. 5 and 6, Table IV. The same generalisation applies to metal containing antimony (Table IV.). Increase of oxygen shows no definite effect on the tensile strength, but causes a marked decrease in elongation.

INFLUENCE OF OXYGEN ON THE PHYSICAL PROPERTIES.

Hardness.—The relative hardness of the cast ingots was taken by means of the Shore scleroscope, using the intensifier hammer. The author has pointed out that the physical property really measured by this instrument appears to be the coefficient of restitution between the hammer and the material to be tested. Under certain conditions (generally fulfilled by metals in the cast or annealed state) this quantity is proportional to the hardness as measured by the scratch test.* The values of the relative hardness of the alloys examined are given in Tables I. and II. To these may be added:—

Copper with Oxygen.		Copper with Arsenic.†		Copper with Antimony.†	
Oxygen, per Cent.	Relative Hardness.	Arsenic, per Cent.	Relative Hardness.	Antimony. per Cent.	Relative Hardness.
0·04	7·5	0·05	8·0	1·0	8
0·32	11·5	0·40	9·0	...	...
...	...	1·50	10·0	...	...

The values are plotted in Figs. 5 and 6, in which lines of equal hardness are approximately indicated.

The addition of arsenic or antimony to pure copper hardens it; the effect of either on copper containing oxygen is first to diminish and then increase its hardness. The addition of oxygen to arsenical copper is without any marked influence on the hardness until it reaches a limit depending on the

* *Proceedings of the Institution of Civil Engineers*, 1910, vol. clxxxi. pp. 478-489.

† Hiorns and Lamb, *Journal of the Society of Chemical Industry*, 1909, vol. xxviii. pp. 452 and 454.

percentage of arsenic, when the hardness rapidly increases. Thus copper, with 0.4 per cent. arsenic and 0.3 per cent. oxygen, is quite as soft as, if not a little softer than, a

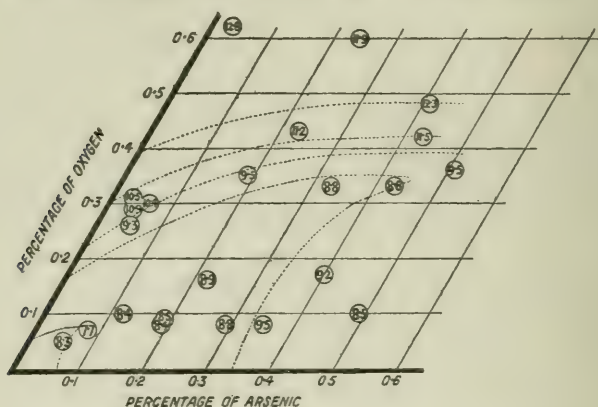


FIG. 5.—Copper with Oxygen and Arsenic. Relative Hardness.

similar metal free from oxygen. The limit of the percentage of oxygen which does not noticeably affect the hardness rises to about 0.35 per cent. as the arsenic increases to

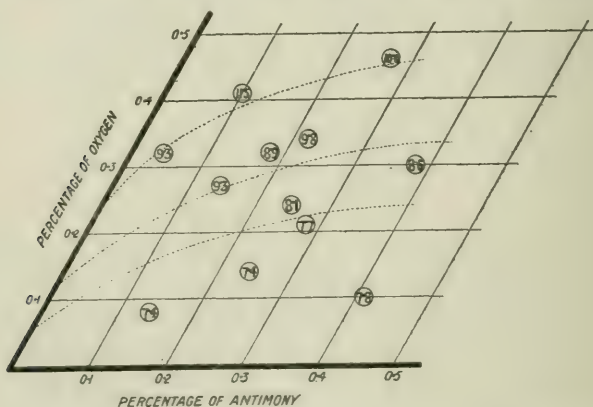


FIG. 6.—Copper with Oxygen and Antimony. Relative Hardness.

0.5 per cent. In a similar way antimony first diminishes and afterwards increases the hardness of copper containing

oxygen, while quite a low percentage of oxygen begins to harden copper containing antimony.

The hardness found after rolling down to about 0.15 inch was unreasonably high (30 to 40) on the scleroscope scale, but the values given after annealing agreed almost identically with those for the cast metal.

Conductivity for Electricity.—For purposes of comparison it is necessary to know the conductivity of copper containing only arsenic or antimony without oxygen. The most complete series of determinations within the limits of composition required is that of Hiorns and Lamb.* Their results for arsenic are in agreement with those of other observers, but for antimony they are somewhat irregular, moreover different workers have obtained divergent results.† With regard to the effect of oxygen, Addicks† concludes that the conductivity of pure copper is slightly increased by the presence of 0.05 per cent. of oxygen, and returns to its original value with 0.10 per cent.

Peters,‡ however, finds that “while the proportion of cuprous oxide found in ordinary good refined copper does not appear to diminish its electrical conductivity (it may even increase it slightly), yet the very highest conductivity tests are yielded by copper which contains no determinable oxygen.”

Hofman, Hayden, and Hallowell§ state that the presence of oxygen improves the conductivity of tough-pitch copper.

Measurement of Resistance.—The resistance of a definite length of a number of wires made as described above, was measured by the Wheatstone bridge method. The diameters of the wires were afterwards obtained by weighing a measured length in air and water. Tables V. and VI. give the specific resistance of the wires in C.G.S. units (ohms $\times 10^{-9}$). The relative conductivity is calculated from these and from

* Hiorns and Lamb, *Journal of the Society of Chemical Industry*, 1909, vol. xxviii, pp. 453-454.

† Hampe, *Chemiker Zeitung*, 1892, pp. 726-728; Addicks, *Transactions of the American Institute of Mining Engineers*, 1905, vol. xxxvi, p. 18; Guertler, *Zeitschrift für anorganische Chemie*, 1906, vol. li, 392; 1907, vol. liv, p. 58. The latter deals chiefly with larger proportions of arsenic and antimony: his curve for arsenic shows a higher relative conductivity.

‡ “Principles of Copper Smelting,” 1907, p. 492.

§ *Transactions of the American Institute of Mining Engineers*, 1907, vol. xxxviii, p. 147.

Hiorns and Lamb's value for pure copper; and since all measurements were not made at the same temperature, the latter is corrected for comparison by the temperature coefficient for pure copper, viz. $R_t = R_0 (1 + 0.00416 t)$.* For comparison, the tables also give Hiorns' values for the relative conductivity of the oxygen-free metal of the same arsenic or antimony content.

In every case in the arsenic series it will be noticed that the conductivity is less than that of a similar metal with no oxygen. In the presence of antimony, however, the effect of oxygen is to raise the conductivity. In order to check this result the measurements were repeated on fresh wires drawn from strips of the same ingot. For the production of these the author is indebted to Mr. H. I. Coe: they are marked (b) in Table VI. The post-office box used had been carefully standardised. Filings from each of the wires were taken for analysis; it will be seen that very little change in composition occurred during the operation of drawing; but making allowance for the possible slight difference in composition, the conductivity of the two sets of wires shows very fair agreement. The quantitative effect of oxygen is not apparent from these results, and the author hopes to make a further series of more accurate measurements to decide this.

INFLUENCE OF OXYGEN ON THE MICROSTRUCTURE.

Specimens cut from the ingots were polished and etched by means of a 10 per cent. solution of ammonium persulphate. The photographs (Plate XX.) were all taken by direct light.

Micrograph 1.—Is typical of cast metal containing arsenic with a low percentage of oxygen. The boundaries of the "cores" are very distinct on account of the rapidity of cooling. A similar metal containing antimony is shown in micrograph 4.

Micrograph 2.—Copper containing oxygen with low arsenic or antimony shows dendrites of copper embedded in a ground-mass of copper and cuprous oxide, not showing a eutectic structure but occurring in isolated globules.

Micrograph 3.—With more arsenic or antimony, as the

* Swan and Rhodin, *Proceedings of the Royal Society*, 1894, vol. lvi. p. 81.

TABLE V.

No.	Composition.		Length, Centimetres.	Diameter, Centimetres.	Resistance, ohms.	Specific Resistance, C.G.S. Units.	Tempera- ture, Degrees C.	Relative Conductivity (Cu=100).	Relative Conductivity, Copper-Arsenic without Oxygen (Hiorns).
	Oxygen, per Cent.	Arsenic, per Cent.							
B 1	.	0.10	0.49	0.0820	0.1312	4690	18	35.2	42.4
C 2	.	0.42	0.43	0.0826	0.0775	4251	17	38.7	45.1
B 3	.	0.17	0.40	0.0861	0.0850	3843	18	46.8	46.8
B 2	.	0.16	0.22	0.0863	0.0926	3178	18	52.0	59.5
B 5	.	0.30	0.06	0.0860	0.0261	2485	18	66.4	77.3
C 1	.	0.26	0.05	0.0831	0.0672	2169	17	75.8	79.4

TABLE VI.

No.	Composition.		Length, Centimetres.	Diameter, Centimetres.	Resistance, Ohms.	Specific Resistance, C.G.S. Units.	Relative Conductivity (Cu=100).	Relative Conductivity, Copper-Antimony without Oxygen (Hiorns).
	Oxygen, per Cent.	Antimony, per Cent.						
A 3.	$\left\{ \begin{array}{l} a \\ b \end{array} \right.$	$\left\{ \begin{array}{l} 0.27 \\ 0.27 \end{array} \right.$	168.0 139.2	0.0825 0.0832	0.0580 0.0482	1847 1889	89.4 } 88.5 87.7 }	80.0
B 1.	$\left\{ \begin{array}{l} a \\ b \end{array} \right.$	$\left\{ \begin{array}{l} 0.08 \\ 0.08 \end{array} \right.$	73.7 79.6	0.0860 0.0836	0.0237 0.0269	1871 1854	88.1 } 88.7 89.3 }	77.5
A 6.	$\left\{ \begin{array}{l} a \\ b \end{array} \right.$	$\left\{ \begin{array}{l} 0.32 \\ 0.30 \end{array} \right.$	224.8 98.3	0.0830 0.0834	0.0798 0.0350	1919 1934	86.1 } 85.8 85.6 }	73.0
B 2.	$\left\{ \begin{array}{l} a \\ b \end{array} \right.$	$\left\{ \begin{array}{l} 0.41 \\ 0.10 \end{array} \right.$	260.7 226.0	0.0862 0.0837	0.1173 0.1052	2629 2564	62.7 } 63.6 64.6 }	58.0

* Analyses of the wires given.

(a) Temperature 17.5° C.; (b) Temperature 18.6° C.

oxygen increases the cores pass into a dendritic form, the boundaries become pitted, and finally approximate in appearance to the oxide boundaries in micrograph 2. Professor Huntington has published a micrograph similar to No. 3, but with less oxygen.* The structure of the boundaries is shown better at a higher magnification. The effect of oxygen is similar in the presence of arsenic and of antimony. The first effect of oxygen is to produce a curious ringlike formation which appears in the boundaries (micrograph 5). These develop into globular masses as the oxygen rises (micrograph 6), and increase in number until they fill the arsenic or antimony-rich boundaries.

In conclusion, the author wishes to express his indebtedness to Mr. J. Cooper Trill for assistance in making the tensile tests; to Mr. A. H. Hiorns for valuable advice, and the benefit of his judgment in the malleability tests; and to Professor A. A. Read for the interest he has taken in the progress of the work.

APPENDIX.

ON THE METHODS OF DETERMINATION OF OXYGEN IN COPPER.

Methods proposed for the determination of oxygen in copper may be classified in two groups according as they have for their object:—

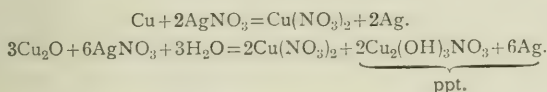
1. The estimation of cuprous oxide;
2. The estimation of total oxygen.

1. *Estimation of Cuprous Oxide.*—This depends on the difference in the behaviour of copper and cuprous oxide towards various reagents, notably (a) silver nitrate; (b) dilute hydrochloric acid; (c) ammonia.

(a) *Silver Nitrate methods.*—Cuprous oxide behaves towards a solution of silver nitrate exactly as a mixture of copper and

* *Journal of the Institute of Metals*, No. 1, 1910, vol. iii. p. 84.

cupric oxide would do—that is, produces a mixed precipitate of silver and a basic copper salt.⁽¹⁾ This is the foundation of Hampe's method,⁽³⁾ in which thinly rolled or finely filed copper is treated for twenty-four to thirty-six hours with cold dilute silver nitrate solution free from acid. The reaction is:—



The copper existing as Cu_2O is found by multiplying the copper in the precipitate by $\frac{3}{2}$. This method replaced Auel's process.⁽²⁾ The reaction given above has been disputed by many,^(4, 6, 7, 9) but was verified by Sabatier⁽¹⁰⁾ and by Hampe^(5, 8) himself, who points out the necessary conditions, chief of which are:—

- (i.) absence of acid;
- (ii.) a solution of silver nitrate not stronger than 60 per cent.; and
- (iii.) a temperature of 0°C . throughout.

(b) Dilute Acid method.⁽¹¹⁾—Copper is treated in a flask fitted with a Bunsen valve with dilute hydrochloric acid, some pieces of marble being added to replace air by CO_2 . It is stated that only copper in the form of cuprous oxide goes into solution.

(c) Ammonia method.⁽¹²⁾—Cuprous oxide is soluble in ammonia in the absence of oxygen, while copper is insoluble. The copper in the form of fine drillings or filings is treated with ammonia in a suitable apparatus, and the copper which passes into solution is estimated.

Arsenic and antimony when present also pass into solution⁽¹³⁾ probably in the form of oxides either free or combined with cuprous oxide. In all the above methods there is the uncertainty as to whether the cuprous oxide actually found exists in the copper wholly as free oxide or partly combined with oxides of arsenic, antimony, &c.

2. *Estimation of total Oxygen*.—The principal methods are given in the following table:—

Method.	Substance weighed.	Authority.
1. Copper heated in a current of hydrogen .	Water	(Dumas) ⁽¹⁶⁾
2. Copper heated in a current of hydrogen .	Copper	Hampe ⁽¹⁹⁾ , Murmann ⁽²⁰⁾ , Archbutt ⁽²¹⁾
3. Copper melted in a current of hydrogen .	Water	Blount ⁽²³⁾
4. Copper melted with tin in a current of hydrogen	Water	Dickson ⁽²⁴⁾
5. Copper heated in a current of carbon monoxide	Copper	Murmann ⁽²⁰⁾
6. Copper melted with tin in a current of carbon monoxide	Carbon dioxide	Lucas ⁽²⁵⁾

The main points of difference appear to be in regard to—

- (i.) The preparation and size of the sample for analysis.
- (ii.) The temperature to which the metal should be heated.
- (iii.) The reducing agent to be used.
- (iv.) The substance to be weighed.

(i.) Attention has been paid to this point by Archbutt ⁽²²⁾, who finds that the best form is thin bright turnings. Larger pieces may be used if sufficient time is allowed for their reduction. Surface oxidation must be avoided, hence filings should not be used. Thin strips are a good form if a sample can be so taken, as these can readily be cleaned with emery. Johnson ⁽²⁶⁾ washes the sample with dilute nitric acid, then ammonia. In view of the fact that such reagents readily attack cuprous oxide, this seems a dangerous practice, especially when the oxygen content is high. With the use of fresh bright turnings or drillings, carefully obtained with a lathe working at low gear to avoid heating, there is little danger of surface oxidation or even of grease, which, however, can easily be removed by washing with ether.

(ii.) Archbutt ⁽²²⁾ found in the case of hydrogen that provided the tube is heated to redness, a further increase in temperature is of no advantage. He showed that it is unnecessary to fuse the metal.

(iii.) The only reducing agents suggested have been hydrogen and carbon monoxide. For reasons of convenience in preparation, hydrogen is to be preferred: reduction by hydrogen also takes place more rapidly. ⁽²⁰⁾

(iv.) There seems to be a general consensus of opinion in favour of the measurement of the loss of weight of the copper, rather than the weight of water formed. For the former method the hydrogen need not be absolutely free from oxygen, as it must for the latter. On the other hand, since arsenic, antimony, and bismuth are expelled from the copper by heat, and form a mirror on the tube, it is necessary to weigh tube and copper. The result depends therefore on a small difference in a large total weight: a large surface is exposed during weighing for the condensation of moisture from the air, and this surface is subjected between the weighings to a high temperature which may at least cause an alteration to its character sufficient to affect seriously the quantity of moisture so deposited. When sulphur is present, part of the loss of weight is due to its volatilisation as H_2S , and this must be corrected for. ^(14, 15, 18, 19)

Method of Analysis Employed.—Hydrogen from zinc and sulphuric acid was purified by passing through U-tubes * containing respectively glass soaked in silver nitrate solution, potash pumice, and pumice soaked in strong sulphuric acid, then through a plug of heated platinised asbestos to convert any oxygen present into water, which was removed by another U-tube of pumice and sulphuric acid. The hydrogen was under pressure up to the screw clip A, by which its flow was regulated. A small gas furnace was used for heating up the Jena glass tube in which the copper was placed. The water formed was absorbed in a stoppered U-tube containing pumice and sulphuric acid: to this was attached a guard tube and then an aspirator. From 5 to 10 grammes of copper in the form of fine turnings or drillings were weighed out into a porcelain boat and inserted into the Jena glass tube. The guard tube was attached and hydrogen aspirated through. Meanwhile the absorption tube (filled with pure hydrogen) was weighed after being wiped on a silk cloth and allowed to remain in the balance case for fifteen minutes. About 1 litre of hydrogen having been aspirated through, the clip B was closed to allow the pressure in the tubes to reach atmospheric :

* These are best supported on a wooden stand similar to that described by Arnold and Ibbotson in their "Analysis of Steelworks Material" (1907), p. 30.

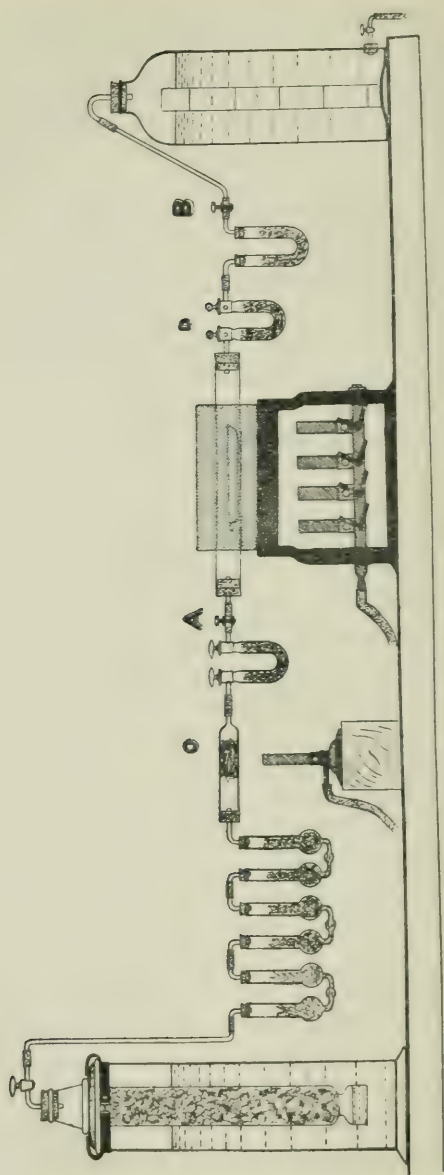


FIG. 7.

the guard tube was removed and the absorption tube inserted into the rubber cork and connected up with the aspirator. Hydrogen was aspirated through for a further twenty minutes, the stream being regulated by the clip A. The copper was heated for about one hour in a slow current of hydrogen, then allowed to cool while a further litre was passed through, after which the current was stopped by closing the clip B, and then the taps of the absorption tube. After disconnecting the aspirator, the absorption tube (which now contained hydrogen at increased pressure) was allowed to blow off into the guard tube by momentarily opening the tap: it was then removed and weighed with the same precautions as before. The absorption tube was always weighed full of hydrogen at approximately atmospheric pressure; this makes it unnecessary to introduce air into the apparatus, and is a great convenience when a number of estimations have to be done. No error is introduced by difference of pressure: to produce an alteration of 0.0001 gramme in the weight of hydrogen in the tube used would require a change of pressure of 40 millimetres of mercury. Blank experiments extending over the same time were carried out at intervals; in these the absorption tube gained from 0.1 to about 0.3 milligramme; only once did it exceed the latter figure, which represents 0.0027 per cent. of oxygen on 10 grammes. This is mainly due to diffusion of oxygen or moisture through the rubber joints and the uncertainty as to their constant dryness.⁽¹⁷⁾ It may, if desired, be entirely overcome by the use of ground glass joints between C and D. Phosphorus pentoxide may be used for drying instead of sulphuric acid: in any case the same drying agent must be used in the entrance and exit tubes. Presence of sulphur would lead to irregular results with sulphuric acid on account of the action of the latter on sulphuretted hydrogen.

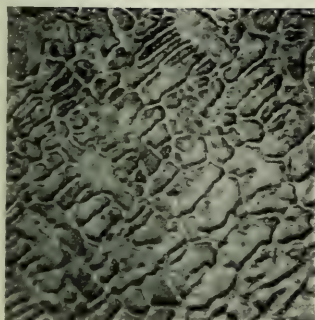
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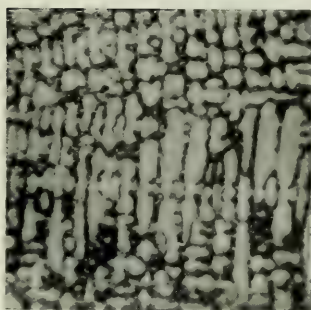
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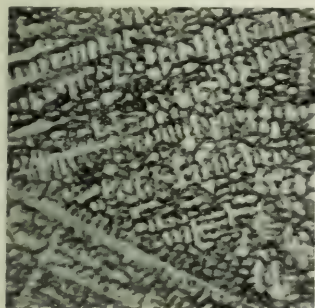
MICROGRAPH No. 1.

Copper containing 0.10 per cent. Oxygen and 0.49 per cent. Arsenic, as cast. Magnified 70 diameters.



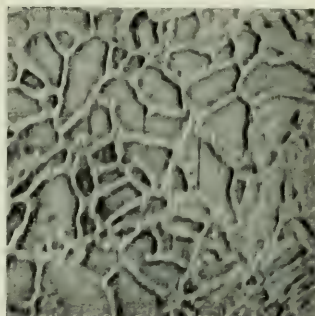
MICROGRAPH No. 2.

Copper containing 0.31 per cent. Oxygen and 0.03 per cent. Arsenic, as cast. Magnified 70 diameters.



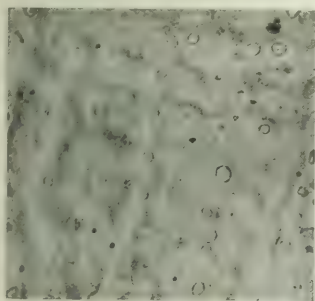
MICROGRAPH No. 3.

Copper containing 0.33 per cent. Oxygen and 0.43 per cent. Arsenic, as cast. Magnified 70 diameters.



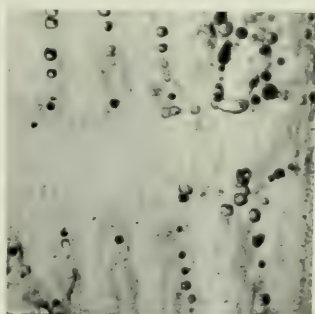
MICROGRAPH No. 4.

Copper containing 0.10 per cent. Oxygen and 0.41 per cent. Antimony, as cast. Magnified 70 diameters.



MICROGRAPH No. 5.

Copper containing 0.10 per cent. Oxygen and 0.49 per cent. Arsenic, as cast. (Same as No. 1.) Magnified 300 diameters.



MICROGRAPH No. 6.

Copper containing 0.14 per cent. Oxygen and 0.24 per cent. Antimony, as cast. Magnified 300 diameters.

DISCUSSION.

Sir GERARD MUNTZ, Bart., Past-President, in opening the discussion, said he was very much interested when he saw the title of the paper, because it might be within the recollection of some of the members that for the last two or three years he had been rubbing it in at the Institute that it was no good giving papers on the effect of arsenic or other materials on copper and ignoring altogether the proportion of oxygen therein contained. On looking at the paper to see whether it confirmed his experience on the subject, he found that to a large extent the author's experiments and deductions did so in regard to the question of the proportion of oxygen and arsenic, with one very remarkable exception, namely, that the whole of the author's oxygen contents were one place of decimals to the left compared with where he (Sir Gerard) would have placed them. The exception was sample 5 in Table IV. on p. 226, where the content of oxygen was given as 0.03. That was about the content of oxygen that he would expect to find. He did not profess to be a chemist himself; in fact, he depended upon his chemical staff to tell him the oxygen contents, and the figures they gave him on which he worked were, with the one exception to which he had called attention, one decimal place smaller than those given by the author. With that exception the paper bore out very largely his own experience of the effect of oxygen and arsenic in combination with copper. He would say, speaking as a practical manufacturer, that a good oxygen content for a 0.5 per cent of arsenic in copper would be about 0.02 to 0.015. If a higher percentage of oxygen was obtained it would tend, as the author pointed out, to increase the tensile strength and to lower the elongation very rapidly. On the other hand, if the oxygen content was reduced below 0.015 it would be found that a material would be obtained which was beautifully ductile and very soft, but of very little practical value. He was exceedingly pleased that the subject had been brought forward, because he desired to impress upon the engineering world, especially his friends in the railway world, the great importance of the question of arranging the oxygen content when they specified the arsenic content, because if they did not take any notice of the oxygen, it was not much good their taking any notice of the arsenic.

Mr. LEONARD ARCHBUTT, Member of Council, desired to call attention to the statement on page 235, in which the author made the following reference to the estimation of oxygen in copper: "There seems to be a general consensus of opinion in favour of the measurement of the loss of weight of the copper rather than the weight of water formed." The author proceeded to give a good reason for that, namely, "For the former method the hydrogen need not be absolutely free from oxygen, as it must for the latter." One reason given for weighing the water instead of determining the loss of weight of the copper, was that there was a large mass of material to be weighed for a small loss of weight. But

was it not a fact that the absorption apparatus for the water weighed almost as heavily as the tube containing the copper? As to the other reasons given, if the author would refer to his (Mr. Archbutt's) paper on the subject, he would see that almost exactly the same results were obtained, whether the oxygen were determined by the loss of weight or by the weight of the water formed. There was no increase in accuracy by weighing the water, and there certainly was a great deal more labour and trouble involved. He would, therefore, like to ask why the author adopted the method of weighing the water. With regard to what Sir Gerard Muntz had just said, did he understand Sir Gerard to suggest that railway companies should specify the amount of oxygen?

Sir GERARD MUNTZ said he did not wish them to do so; he did not want them to specify anything.

Mr. ARCHBUTT, continuing, said he thought Sir Gerard would agree that, if the oxygen in copper were to be specified, it would be a very difficult thing for the manufacturers to comply with the specifications, and a foolish step to take. As users they knew the oxygen was there, and if the percentage of arsenic required was specified, the oxygen content must be left to the manufacturer, whose business it was to bring the metal to the proper pitch. Exactly the same remarks applied to specifications for steel, in regard to which he did not believe in specifying full chemical analyses and full mechanical tests. Something must be left to the manufacturer. If the engineer wished to specify full mechanical tests he should limit himself in the chemical specification to impurities. If, as for instance in the case of spring steels, he chose to give a complete chemical specification, he thought the mechanical specification should be no more than was necessary to ensure sound and well-made material.

Sir GERARD MUNTZ said he did not want the engineers to ask for anything more than they asked for at present.

Mr. F. JOHNSON, M.Sc. (Swansea), said that the author's paper dealt with a subject in which he had been specially interested, and it gave the results of careful work, the scientific value of which was indisputable. The practical man, however, was inclined to regard with indifference, as a rule, experiments carried out with material with which he was not directly concerned. How long that unfortunate state of things would continue depended largely on the tact of the missionary scientists of the Institute of Metals. Personally he had taken the very keenest interest in the paper, as it bore largely on work of a somewhat similar nature which he had carried out himself, but it was easy to understand the point of view of the practical man who saw no relation between curves plotted to show the influence of an element such as oxygen (he was speaking from the manufacturing practical man's point of view), and the material with which he had to deal, which contained very much less oxygen than that contained in most of the material of the author's experiments.

Those manufacturing firms which engaged the services of expert refiners found it a comparatively simple matter, owing to their experience, to control the percentage of oxygen in copper. What did bother them at times was not the percentage of oxygen so much as the percentage of accidental impurities. The author had made a very wise choice indeed in deciding to experiment on arsenic and antimony, because arsenic was very often added to copper, and was most beneficial and, in some cases, essential. Antimony was more or less of a "dark horse," but it invariably had the effect of hardening and increasing the tensile strength of arsenical copper. That influence in conjunction with arsenic was a matter yet to be studied. While not condemning antimony, he (Mr. Johnson) considered that it certainly had an influence on copper which was less beneficial than arsenic, and the results of that influence became more pronounced in a detrimental way at a far lower percentage than the percentage of arsenic. On the first page of the paper the author alluded to a paper recently read by himself (Mr. Johnson), and stated that "the study of tough-pitch copper, however, is complicated by the effect of a number of impurities." That was not necessarily so, because electrolytic copper might be used which was in a "tough-pitch" condition and which contained no impurities, practically speaking, at all. What the author probably meant was that the study of commercially tough copper was complicated by those impurities. The author's method of preparing ingots was exactly the reverse of the commercial method. He started with pure copper and then added oxygen to it. A manufacturer started in the refinery with copper saturated with oxygen, and removed as much of that oxygen as he possibly could. He did that by the process of "poling," which in itself could have a very profound effect on the physical properties of the copper, apart altogether from the proportion of oxygen. The method adopted by the author of leaving his metal in the furnace to become "dead melted" was open to the objection that the metal was absorbing still more oxygen than he intended it should have. The author recorded the surface appearances of his ingots, but he (Mr. Johnson) would like to point out that they were true only for the conditions of his experiments, *i.e.* some of the ingots would naturally have a flat surface because they were cooled very rapidly. He did not wish to be too critical, and he quite realised that the author's observations were of very great interest. It should be remembered that in practice, given a constant percentage of arsenic, the "set," *i.e.* the surface appearance of the bar, depended entirely on the percentage of oxygen and gases present. The rolling tests given by the author seemed to him (Mr. Johnson) to be rather unsatisfactory. There was no apparent reason why alloy 5 (Series A) should not roll as well as the others, nor why alloy 6 should be so much worse than alloy 5 (Series B), *i.e.* there was a difference in the latter instance of 0.03 per cent. of arsenic and the oxygen was about constant. That difference of 0.03 per cent. was too trivial to account for the varying behaviour. At the same time the author showed very clearly that arsenic tended to improve the rolling properties of copper otherwise too rich in oxygen,

but that required a lot of explaining. Tentatively he would suggest that the improvement was due to the chemical, and possibly the structural, alteration of the oxide eutectic. Metal so rich in oxygen as 0.3 per cent., however, even if it did roll perfectly, as the author showed it did, was useless owing to its extreme brittleness. With regard to the effect of antimony, the author's results confirmed what he (Mr. Johnson) had pointed out on several occasions,* namely, that oxygen effected a great improvement in copper containing antimony up to a certain point, both in hot and cold rolling. He had given an instance, in the discussion on his paper read at the Autumn Meeting of 1910, of a copper containing 3 per cent. of antimony, which it was possible to draw into wire by the aid of a slight addition of oxygen. The tensile tests carried out by the author on cast material were not so valuable as if they had been carried out on wrought material. Cast copper was very much less used than wrought copper. He was carrying out some researches on the question of antimony in copper, and recently had occasion to test a rolled bar containing 0.5 per cent. of antimony and 0.3 per cent. of oxygen. That rolled bar bore out the author's remarks with regard to the embrittling influence, but it also brought out another point, namely, an increase in tensile strength. The tensile strength of the bar in question was 20 tons per square inch, and it had an elongation of 6 per cent. on 3 inches. That result had been confirmed, and was, as far as he was aware, without parallel so far as impure copper was concerned. In Table III. on page 225 the difference between 6, 5, and 7 required some explanation. With the oxygen practically constant, there was a gain of over 2 tons per square inch, with an increase of only 0.03 per cent. of arsenic, while with a further increase of 0.27 per cent. there was no further gain in the tensile strength. The powerful influence of 0.03 per cent. arsenic at that particular stage was inconceivable, especially since a further increase of 0.27 per cent. had no effect at all. A peculiarity about the microstructure of the rolled bar that he had mentioned was that the cuprous oxide particles were accompanied by a darker oxidised compound of antimony. The antimony was in an oxidised condition undoubtedly, and that dark constituent did not appear in bars free from antimony. It seemed to him that the difference between antimony and arsenic was that where arsenic was present with oxygen, the former existed in solid solution and not as an oxidised compound. In the case of antimony with oxygen, some of the antimony was drawn out from solid solution, and existed as an oxidised compound. In that case higher conductivity was obtained, because an element in solid solution would tend to lower the conductivity more than when that element separated out partly as an oxidised compound.

Mr. GREAVES, in reply, said he was glad the paper had led to such an interesting discussion, but owing to the short time at his disposal he would communicate the majority of his reply in writing. Sir Gerard

* *Journal of the Society of Chemical Industry*, July 1906; also *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 232.

Muntz had referred to the uncommercial nature of the alloys. They were made in the way described, and the process of manufacture was, as Mr. Johnson pointed out, the exact contrary of commercial. They were not commercially but synthetically prepared. With regard to the remarks made by Mr. Archbutt on the analyses, he had no great reason for preferring the method that he gave to the one that gentleman suggested. He desired, however, to call attention to a sentence lower down on the same page as the one that Mr. Archbutt quoted, namely, "a large surface is exposed during weighing for the condensation of moisture from the air, and this surface is subjected between the weighings to a high temperature which may at least cause an alteration to its character sufficient to affect seriously the quantity of moisture so deposited." The absorption tube was a very much more easy thing to weigh, and the surface of the absorption tube was much more likely to remain constant than the tube containing the heated copper. To the remainder of the criticisms he would reply in writing.

COMMUNICATIONS.

Mr. F. JOHNSON, M.Sc. (Swansea), wrote, in continuation of his remarks made at the meeting, that with regard to the tensile test to which he had then referred, he had omitted to mention that the bar in question had been subjected to a certain amount of cold work, and how far that had influenced the result he was not yet able to say.

Referring to the author's results on electrical conductivity, which showed that the presence of oxygen in the arsenic series lowered the conductivity, and that in the antimony series it raised the conductivity, he (Mr. Johnson) would like to know if the author had recognised the existence of those dark antimonial "oxidules" to which he (Mr. Johnson) had drawn attention at the meeting.

There was no doubt about their existence in copper-antimony-oxygen alloys, and the writer would welcome the author's opinion as to their effect on the conductivity. It seemed clear that an impurity existing in isolated globules (in an oxidised condition) would have much less influence on the conductivity than when existing in solid solution.

He was glad to know from the author's results that oxygen lowered the conductivity of the copper-arsenic bars, for the results confirmed the theory which the writer had previously held, viz. that in arsenical copper of the usual compositions found in commerce, the arsenic was all in solid solution, and all the oxygen existed as Cu_2O . Therefore one would expect cuprous oxide to exert its own influence in lowering the conductivity, when added to copper containing an element which persisted in remaining entirely in solid solution, in spite of the addition of cuprous oxide.

The author's tensile tests would have conveyed more information had they been accompanied by similar tests on blank bars of pure copper.

It was a good thing to know, and it was a thing to which he could bear adequate testimony, that the proportion of cuprous oxide found in good refined copper did not appreciably diminish its conductivity.

With regard to the determination of oxygen in copper, he believed that less error was involved by determining the loss in weight of the copper, if precautions were taken to prevent escape of volatile elements from the glass tube. A silica tube was used by the writer, with a bulb in the centre to hold the drillings (or preferably pieces of rolled strip).

The amount of copper taken by the author seemed too small for the lower percentages of oxygen. The experimental errors involved were lessened by taking 20 to 25 grammes of copper, or more, which could easily be accommodated in the bulb above mentioned.

The shape of the latter was as shown in the following sketch.



The ends could be fitted with corks, or tapered down to take the indiarubber tubing.

Mr. H. J. YOUNG (Wallsend-on-Tyne) wrote giving his experience of the determination of oxygen in copper, a matter dealt with by the author in the appendix to his paper. Some years ago he (Mr. Young) had charge of determinations which had to be carried out by a method which was considered a standard. Filed copper, freed from iron, was washed in water, alcohol, and ether, and weighed in a Jena glass bulb. The latter was attached to a typical combustion apparatus, carbon-dioxide being passed over until all air had gone, when the sample was slightly warmed, and allowed to cool in an atmosphere of carbon-dioxide; then the carbon-dioxide was replaced by air, and the bulb and U-tube weighed ready for combustion. Hydrogen was next passed to expel all air, and the bulb raised to a full red heat for fifteen minutes, hydrogen passing the whole time and until cool. Finally the bulb and U-tube were weighed after being filled with air. Every precaution was taken to insure accuracy.

In his opinion the results obtained from those estimations were valueless, the loss and gain of weight of the bulb and U-tubes differed fantastically in different experiments with the same metal, and never even from the loss of weight alone did he get several concordant results which could be guaranteed were accurate. It should be added that the experiments were carried out upon the coppers of commerce, which possibly contained no more than 0.1 per cent. of oxygen, and none had added oxide.

The details given by Mr. Greaves of his estimations were by no means the least valuable part of his paper, and it was pleasing to note his care to avoid depreciation of technique, upon which the value of scientific argument so often depended.

Mr. GREAVES, in reply to the remarks and written communication of Mr. Johnson, wrote that he agreed that slight variations in tensile strength could be determined reliably only by tests on rolled and annealed bars, nevertheless the results with the cast metal sufficiently brought out the embrittling influence of the oxygen.

He had recognised the dark, quickly etching globules which occur in the antimony-rich boundaries and are greater in number as the oxygen increases, but would point out that a similar appearance also characterised the arsenical metals.

Though he had followed with interest Mr. Johnson's suggestions, he could not help regarding any definite pronouncement as to the mode of action of arsenic or antimony and oxygen in influencing the mechanical and physical properties of copper, as premature in view of the present slender knowledge of the chemical relations of these elements in the presence of copper.

With regard to Mr. Young's experiences in determining oxygen in copper, he (the author) had found, using dry electrolytic copper, that equal results were arrived at by taking the loss in weight of the metal, or the gain in weight of the absorption tube, in the same determination. The work of Mr. Archbutt showed that the two methods led to consistent results with ordinary commercial coppers.

A METALLOGRAPHIC HYGROSCOPE.*

BY CARL BENEDICKS AND RAGNAR ARPI.

(Contribution from the Physical Laboratory of the University of Stockholm.)

WHILST making some experiments upon a zinc-antimony alloy in quite a different connection, one of the authors (B.) observed an interesting phenomenon, which may be described here, although its bearing lies rather in a physical direction.

On attempting to etch a ground and polished specimen of an alloy with 9 per cent. zinc with gaseous hydrochloric acid, by simply holding it for some thirty seconds over a vessel containing the ordinary aqueous solution of the acid, it was found that instead of attacking the polished surface evenly and uniformly, the acid vapours condensed upon it in separate, minute drops. Each of these drops, if allowed to evaporate under ordinary atmospheric conditions, leaves behind a thin layer displaying bright interference colours, as shown by the autochrome photograph (Plate I.). The first rather striking point to be noticed is that these interference colours are by no means constant. The direct cause of the colour-changes was traced to the *vicinity of the hands*: on bringing one finger up to the specimen from a distance, the interference rings suddenly changed to a higher order, the change being accompanied by a most characteristic play of colours. This was particularly noticed on those drops which happened to be upon the eutectic portions of the alloy.

This phenomenon is evidently due to the fact that the metallic chloride formed in every drop remains as a highly hygroscopic thin film, the thickness of which must be a function of the hygroscopic conditions obtaining in the surrounding air. The specimen from this point of view can be regarded as rather a sensitive hygroscope.

Etching with alcoholic hydrochloric acid (one part of concentrated aqueous acid to ninety-nine parts of alcohol) with-

* Read at Annual General Meeting, London, January 17, 1912.

PLATE I



Reproduction from Autochrome Photograph
showing Interference Colours on Acid-
covered Surface of Zinc-antimony Alloy.



out subsequent washing produced nearly the same effect, except that the outlines of the drops were not the same. A series of different zinc-antimony alloys were etched with the following result:—

Concentration.					Hygroscopic Film.
20	per cent.	zinc (near eutectic I.)	.	.	Suitable.
27	"	"	.	.	"
35	"	" (near Zn-Sb)	.	.	Useless.
45	"	" (" Zn ₃ -Sb ₂)	.	.	Bad.
95	"	" (" eutectic II.)	.	.	"
100	"	" (i.e. pure zinc)	.	.	"

The alloys containing from 20 to 27 per cent. zinc were probably better than the alloy first tried; in any case, differences in etching seem to be of greater moment than the exact concentration of the alloy.

Even when etching with alcoholic hydrochloric acid, the chloride film soon segregates into distinct drops, owing probably to the impossibility of excluding every trace of grease. It appears probable that the salt film is composed essentially of zinc chloride and of water, the antimony being but slightly attacked.

Some further experiments were carried out in which, in place of a metallographic specimen, a dark glass plate was used. A thin layer of a hygroscopic substance, such as phosphorus pentoxide or calcium chloride, was spread over this, but with very little result. The main difficulty is to prepare and maintain the glass plate in such a high degree of purity that the liquid will adhere to it as a thin layer, and not coalesce into thick drops. The power of adhering to the etched surface is much stronger in the case of the zinc alloy.

Some measurements were made upon the alloy with 20 per cent. zinc. A small specimen of the alloy was soldered into a metal tube, and a narrow hole was bored just under the polished surface to take a copper-constantan thermocouple. A slow stream of cooled water was allowed to flow through the tube, and hence the temperature of the specimen, as measured by the thermocouple, could be varied at will. A low-power objective was used on the microscope, giving

a clearance of about 8 millimetres to the specimen and the temperature was noted when new rings developed in the middle of the sensitive spot.

The following figures were obtained:—

Number of Interference Rings.	Temperature, Degrees Centigrade.
1	17.5
2	13.0
3	11.0
4	10.0
5	9.5
6	8.6
7	8.5

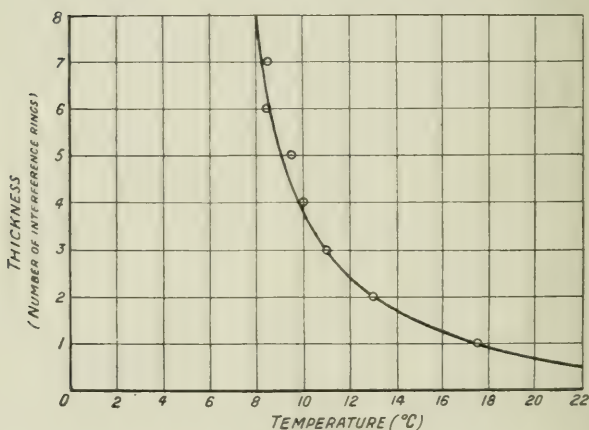


FIG. 1.

As seen by the curve (Fig. 1), the connection between temperature and thickness of layer is quite a regular one. The thickness increases with falling temperature at a rate which is the higher the nearer the temperature approaches to the dew-point; the curve must have as asymptote a vertical line passing through the dew-point. It follows that this method can be used for determining the dew-point, although it may not be easy to control. Experiments are in hand with a view to using pure water instead of a hygroscopic film.

THE THIRD ANNUAL DINNER

THE Third Annual Dinner was held at the Criterion Restaurant, Piccadilly, W., on Tuesday evening, January 16, 1912, Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S., Vice-President, occupying the chair.

There was an attendance of guests and members numbering about 150, amongst whom were:—

Mr. ARTHUR BALFOUR (*Master Cutler*).

Colonel Sir HILARO BARLOW, Bart., R.A. (*Chief Superintendent of the Royal Laboratory, Woolwich Arsenal*).

Mr. W. DIXON (*President, The West of Scotland Iron and Steel Institute*).

Sir H. F. DONALDSON, K.C.B. (*Chief Superintendent, Royal Ordnance Factory, Woolwich Arsenal*).

Mr. E. B. ELLINGTON (*President, The Institution of Mechanical Engineers*).

Principal W. H. HADOW (*Armstrong College*).

Mr. E. HALL-BROWN (*President, The Institution of Engineers and Shipbuilders in Scotland*).

Sir ALFRED KEOGH, K.C.B., LL.D. (*Rector, Imperial College of Science and Technology*).

Dr. RUDOLPH MESSEL (*President, The Society of Chemical Industry*).

Colonel R. SAXTON-WHITE, V.D. (*President, North-East Coast Institution of Engineers and Shipbuilders*).

Mr. H. L. SULMAN (*President, The Institution of Mining and Metallurgy*).

Sir W. TILDEN, F.R.S.

Sir GERARD A. MUNTZ, Bart. (*Past-President*).

Sir WILLIAM H. WHITE, K.C.B., LL.D., F.R.S. (*Past-President*).

Professor H. C. H. CARPENTER, M.A., Ph.D. (*Vice-President*).

Professor A. K. HUNTINGTON, Assoc. R.S.M. (*Vice-President*).

Mr. W. H. JOHNSON (*Vice-President*).

Professor T. TURNER, M.Sc. (*Honorary Treasurer*).

Mr. L. ARCHBUTT (*Member of Council*).

Mr. G. A. BOEDDICKER (*Member of Council*).

Mr. W. MURRAY MORRISON (*Member of Council*).

Dr. W. ROSENHAIN (*Member of Council*).

The Chairman gave the toast of "His Majesty the King," which was drunk with musical honours.

"THE INSTITUTE OF METALS."

Colonel R. SAXTON-WHITE, V.D. (*President, North-East Coast Institution of Engineers and Shipbuilders*), in proposing the toast, said: It is a very great pleasure, and I take it to be also a very great privilege, to be asked on an occasion such as this to propose prosperity to the Institute of Metals. I wish that I personally were better able to

appreciate the work which is being done by this Institute. It is an Institute such as a horsey man would say was aged three, rising four. If the Institute can present such a gathering as this as an example of the work which it is capable of doing in its third year, what will it do in its thirtieth? I think a special room will have to be designed and built to receive those who will then desire to take part in the proceedings. It has been said that the wise child makes a very careful selection of his parent. I think this Institute has been particularly fortunate in the gentlemen you have called upon to act as your official Parents or Presidents, and I think it is to that fact that the very great success of the Institute is almost entirely due. In selecting Sir William White as your first President, I am sure that no child of however abnormal growth and intelligence could possibly have selected a more worthy man to fill the position of the first President of a new Institution. Sir William White was succeeded in turn by Sir Gerard Muntz, and I am perfectly certain that what Sir Gerard has done for this Institute cannot be measured by small efforts. He has done a very great work for the Institute; he has forwarded its interests in every way. I am sure that you all regret the absence of your new President, Professor Gowland, and we trust that his indisposition may be of a very temporary nature. Gentlemen, we have in the Chair to-night one of your Vice-Presidents, Engineer Vice-Admiral Sir Henry J. Oram. It does not rest with me to sing the praises of Sir Henry, because the gentlemen whom I am addressing have a very full realisation of the work which Sir Henry has done for the Royal Navy. I have heard of certain requirements and difficulties which he has put in front of metallurgists in connection with condenser tubes. Sir Henry Oram laid down certain standards which our friends dining here to-night found some difficulty perhaps in fulfilling, but, after all, Sir Henry has the very best interests of the Navy of this great country at heart. I therefore have the greatest pleasure in putting forward for your acceptance the toast of "The Institute of Metals," coupling it with very good health, long life, and prosperity to our Chairman, Engineer Vice-Admiral Sir Henry Oram.

The CHAIRMAN (Sir Henry Oram, K.C.B., F.R.S.), in responding, said: Before I make any remarks in reply to the toast of the Institute so kindly proposed by Colonel Saxton-White, I wish briefly to refer to the reason of my presence here to-night. It is of course well known to all of you the serious illness of our newly elected President, Professor Gowland, a gentleman who has worked very hard and given very much of his valuable time to the service of the institute. Professor Gowland, although not able to be with us to-night, in the flesh at any rate, is, I am sure, thinking of us and is with us in spirit, and it will be a graceful act on our part, and one in which I am sure you will all agree, if we send him a message of condolence and sympathy in his illness, and our best wishes for his speedy recovery.

On behalf of the Institute, I must thank Colonel Saxton-White very cordially for the way in which he has referred to the work that we do

at this Institute, and also for the kind remarks he has made about me personally, which I am afraid are not quite deserved. The Institute is now firmly established. It is, as Colonel Saxton-White said, now in its fourth year; and there is no doubt but that it has fulfilled a useful purpose, and contributed by its proceedings to the general advancement of metallurgical science. We are happy in having a considerable number of members who work very hard for its interests, and the result is that both as regards work accomplished, membership, and also finances, the condition of the Institute is a very satisfactory one. The membership is steadily increasing; it is now actually 586, as compared with last year's record of 551. I think, without divulging any Council secrets, I may say that new applications for membership are coming in rapidly, so that we anticipate at the next election, which takes place in April, that we shall have a record ballot list. Let me add that these prospective new members will have the advantage of being able to attend as full-fledged members the May lecture by Sir J. A. Ewing, but they will not be asked for any subscriptions until July. Although the growth of the Institute is fairly satisfactory, our field of usefulness is so extensive that many more new members are necessary to enable the Institute to make effective use of its opportunities. I would like to add a word of caution to the younger members of the metal industries who are eligible for membership, and who may be hesitating as regards joining the Institute. We all have had experience of the contagiousness of example. We have all known it in our private lives: we see its results every day in the labour world, in recurring strikes and troubles of all sorts; and it may be that institutions such as ours are not free from the risk of infection or contagion. Our Council is in close contact with the Councils of the three great Engineering Societies, the Civils, the Mechanicals, and the Electricals, through their members, and I think there is some danger that they may become inoculated and be overcome by the malady now rapidly spreading among technical Institutions, which I may describe as "examination fever." I quite recognise the desirability of gradually supplementing practical requirements by an examination for the younger members, so that my warning to such young men is to hurry up and join the Institute before the Council decides on an examination for membership, which, considering the vast field covered by our Institute, may be made a very troublesome one for intending candidates.

Briefly referring now to one other subject, quite a different one, the research work of the Institution as carried out by the Corrosion Committee. It is gratifying to know that serious practical work by that Committee has now commenced, and that useful results are confidently anticipated from their investigations. But to enable those results to be properly realised considerable expense must be incurred, which, I think, it would be unreasonable to expect a young Society like ours to bear. The Council have therefore asked for subscriptions for this purpose, and I have before me now the list of subscriptions; it was, I believe, published to-day. I must say, Gentlemen, that the list is extremely

disappointing. It amounts all told, subscriptions promised and actually realised, to the sum of £320 only—to be exact, £320, 8s. 3d. There are a great number of wealthy companies and individuals whose names are absent from that list, and I therefore appeal to the scientific and engineering world for a more generous response to this fund. It really is remarkable how little we know of many of our alloys after years of experience. A great deal of valuable work of similar kind has been done by the Institution of Mechanical Engineers, but very much remains which can be usefully undertaken by the Institute of Metals, provided funds are forthcoming. Gentlemen, I am only an understudy here to-night, so I know you will not expect me to detain you long, especially as there are several other speeches to be “worked off” to-night before we go home. I will conclude by hoping that to-morrow we shall have a large attendance at our meeting, when no less than eight very excellent papers are to be read and discussed. Colonel Saxton-White, I thank you very much indeed, and you, gentlemen, for the kind way in which you have received this toast.

“KINDRED SOCIETIES.”

Mr. W. H. JOHNSON (Vice-President), in proposing the toast, said: It is my pleasant duty this evening to propose the toast of “Kindred Societies,” from many of which the Institute of Metals has received great kindness. More especially in that connection would I mention the Institution of Mechanical Engineers. I well remember that the first meeting at which the Institute was inaugurated was held four years ago next February in their building, and by their kind permission. Perhaps I may tell you that, about an hour before that meeting was held, Professor Carpenter and I did one of the best day’s work that ever befell us. We desired to have a good chairman, and we therefore called on Sir William White. Whether it was due to the eloquence of my friend on my right, Professor Carpenter, or to a comprehension of the possible future of the Society in promoting the well-being of mankind, that induced Sir William White to assent to our request, I do not know; but I think you will all allow that that was a good day’s work, for in getting Sir William to preside over that first meeting, and afterwards to be our first President, a sure foundation was laid for the future of the Institute, a foundation which has led to its astonishing and amazing growth, which we trust will continue. Our friends, the Mechanicals, not only obliged us on that day, but ever since they have been good enough to lend us their splendid building in which to hold our meetings. But we have with us to-night the representatives of many other societies. For instance, there is the Society of Chemical Industry, and we look to that Society to bring us many problems such as have been brought to us by other societies. We also naturally looked to the Iron and Steel Institute as a body on which we could model our rules. The Engineers and Shipbuilders have been very willing for us to try to solve the serious and most important problem of the corrosion of marine condenser tubes. We have appointed a committee to investigate the subject; they are now attacking it with all the vigour

of youth, and they are proving that the Institute of Metals is not only a scientific society, but that it is a benefit to mankind in general, and to the kindred societies in particular. I have very great pleasure, therefore, in proposing the health of "Kindred Societies."

Mr. E. HALL-BROWN (President, the Institute of Engineers and Ship-builders in Scotland), in responding, said: It is a great pleasure to be here as a member of a society that can claim kinship with the Institute of Metals. Mr. Johnson has pointed out that from other Institutions you have received benefits, but from the Institute of Engineers and Ship-builders problems. Gentlemen, I think possibly the greater of the two gifts is to provide you with problems which will show the mettle of the Institution. I think it must be a great pleasure to all of us who belong to older societies to associate, as we are doing to-night, with the members of a younger Institution, one that is to be envied for its youth, one that is to be looked up to and admired for its energy and its enthusiasm. The Institute of Metals has begun well, and I have not the least doubt that it will go on and prosper, and that it will increase and be a power in the land and a benefit to mankind generally.

Our Chairman to-night has mentioned that there are several long speeches to be worked off. Well, to be quite honest with you, I had sufficient notice of what I was expected to do to-night, and I prepared what was perhaps rather a long speech; but then I thought, what have they done that I should inflict such a thing upon them? I could not help feeling as I enjoyed your dinner, that it would be a very, very poor return for all your kindness and hospitality to give you such a lecture as was in my mind. You see men are of very different temperaments; I believe doctors divide them into sanguine and bilious. I am afraid I must admit that I belong to the bilious side of the family, and you can easily understand that, as President of an older institution, and one which is perhaps suffering from the stress of years, I do not look upon things in the rosy way that members of this Institute look upon them. It is said sometimes—I hear it whispered at all events—that our institutions have seen their best days and are declining; I hear it said that the same freedom of discussion is not now allowed as it once was; I hear it whispered that there are even villains of deeper dye controlling some of the large and increasing engineering and manufacturing concerns who do not allow those who are so very well qualified to add to the store of our knowledge, to give us the full benefit of their experience. Gentlemen, I hope the day is far distant when any free Briton will allow freedom of speech in engineering or scientific matters to be denied to him. I think the old Book says that you must not muzzle the ox that treadeth out the corn; and to prevent an engineer from talking "shop" will be about the most severe punishment that can possibly be inflicted upon him.

I said I did not intend to make a speech, and I really do not intend to keep you much longer; but I cannot help saying that I hope you will make full use of the earnestness and enthusiasm of youth; that you

will make up your minds that, whatever institution goes down, the Institute of Metals will go up; that everything you put your hand to will be well done, as I am sure it will; that success may attend the deliberations of this Institution; that it may go on from prosperity to prosperity; and that its splendid beginning may lead to a still more glorious career. Gentlemen, I beg to thank you most sincerely for the generous hospitality which I have enjoyed at your board to-night, and for the very kindly way in which this toast has been proposed and honoured.

Dr. RUDOLPH MESSEL (President, the Society of Chemical Industry), who also responded, said: My difficulty in responding to the toast that you have been good enough to propose is, firstly, because I had some prejudice against the Institute when it was founded only a few years ago; secondly, because my task was made more difficult when I perused your President's address this afternoon. He tells us there when metals were first introduced, and he dates the period back to the Neolithic Age. He tells us how copper was first of all produced, more or less accidentally, from stones containing copper surrounding a camp fire, differing from what I had seen stated somewhere else that the discovery of copper was due to the vanity of women. According to my story, malachite was used as a cosmetic by Egyptian women, and some of this material fell into a charcoal fire, thus producing for the first time metallic copper. Which origin is correct, I do not pretend to know; but it seems to me quite clear that copper was born in the unavoidable absence of both the Institute of Metals and of the Society of Chemical Industry. I said to myself, the Institute of Metals, the youngest of societies, I think is a society which occupies itself with metals produced in various parts of the world, but if for so many centuries these metals could go on by themselves, what assistance do they need now? It has turned out that I was quite mistaken. Having been present at your lectures and your meetings, having seen your *Journal*, and heard how its sale has increased, having heard how your numbers have increased, I can see that my original prejudice was not justified, and that you have done most excellently in founding such an Institute. And this is in no small degree due to the excellence and zeal of your officers, and not in the last degree, I am sure, to my old friend, Sir William White, your first President. What was my prejudice? What was my fear in yet another society being established? It was this: I find so many societies do overlapping work. They do work twice over, where, in my opinion, a very great amount of energy could be better employed. Perhaps in an after-dinner talk it is hardly the right and proper thing to approach such serious objects. On the other hand, at charity dinners people open their pockets more widely and give more freely of their wealth; and perhaps at an after-dinner speech of this kind our minds are a little more open and a little more receptive of ideas which at other times we should perhaps look rather askance at. I have always been most anxious that while doing work that is specially appropriate for each particular society, we should try

and avoid this duplicating of work. Quite recently a Congress was held in Paris with that very object. In my opinion it is Utopian. It goes too far. It reminds me of the old story of the People's Palace, which originated from *All Sorts and Conditions of Men*, where everything was to be done for us, so that it was only necessary to put the finishing touch. In my opinion that is going too far. The next Congress on the subject to which I have alluded will be held in Berlin to further consider its problems, and it is in view of that meeting that I desire to bring the matter to your notice so that all may work together and see if anything practical can be done. The question of abstracts is probably foremost. If we could have one central body, say for all English-speaking nations, another for Germany, and another for France, doing such work, we might limit the scope of our societies to the objects for which they were really in the first instance founded. I will not go further into this matter now; I only throw the subject out for the consideration of the Council. Your aims, you must not overlook, are very ambitious, because as an Institute of Metals you have to deal with problems which arise from mechanical, engineering, or chemical points of view, and as we have such various societies as the Society of Chemical Industry, the Shipbuilders, the Engineers, the Mechanical Engineers, and so on, it shows how diversified your aims may become. You have invited me here to-night as the President of the Society of Chemical Industry, and I am very grateful to you for doing so, because your invitation implies the goodwill of your society towards us. I cannot but feel that the value of both societies will be enhanced if we collaborate for the benefit of humanity at large.

"THE GUESTS."

Mr. GEORGE HUGHES, Member of Council, in proposing the toast, said: You have given me an act to perform this evening which has, to my mind, a most gracious purpose, and I must confess that I feel considerably honoured in your confidence. Time, and also my own design, demand that I shall not extend the perfect principles of art in carrying out your behest. I want myself, no doubt the same as you do, to get through this task as expeditiously as possible. Gentlemen, you know the guests who have honoured us this evening, and I think it would be presumption, and perhaps patronising, on my part if I commenced to enumerate their attainments. They are all, I take it, well known to you. But it does seem to me that their presence suggests that we might examine their ruling principles—not in public; that might be too delicate—but we might do it with considerable advantage in the seclusion of our own studies. By doing so, no doubt, we should ascertain the things that they avoid, and the things that they pursue; and it is only a very short step for me to add that "imitation is the sincerest form of flattery." If we members of this new Institution act upon this suggestion, I have no doubt that all the gentlemen before me will very soon make their own position equally as important as that occupied by their guests, and I think that if we assimilate all their knowledge and learning, this young

Institution of ours will be like that great rocky promontory which projects into the sea, the waves continually washing it, but breaking those waves, and directing their course. Those are a few simple thoughts suggested by this toast. We, as an Institution, can direct the course of thought in connection with the subjects which band us together. In short, gentlemen, as Mr. Micawber would say, in one word, the presence of our guests this evening "boosts" us up. Their strength strengthens us, and we no doubt are encouraged by their example. Finally, gentlemen, I wish—and I am sure you will join with me in wishing—that our guests may always obtain that which they most desire. I now have very great pleasure in proposing the toast, coupled with the names of Mr. Arthur Balfour and Sir H. F. Donaldson.

MR. ARTHUR BALFOUR, the Master Cutler, in responding, said: It is a great pleasure to me to have the opportunity of thanking you for your very kind hospitality to-night, not only on my own behalf, but on behalf of the guests in this half of the room. I am going to leave the other half to my friend Sir H. F. Donaldson. I hope that I may take your invitation as a welcome to the new Department for Non-ferrous Metals and Mining which the Sheffield University is now building, and to which I may add that the Drapers' Company of London has given £15,000. We hope that that department of the University will help forward the knowledge of non-ferrous metals, not only in Sheffield, but in England and the whole world. It is always a pleasure to be present at a dinner of this kind, where practical and scientific gentlemen meet, as I feel sure that a Society of this kind is very necessary in these days, so that the practical and scientific gentlemen may exchange ideas, and come to know one another better than they have done in the past. We have taken great pains in Sheffield to get the scientific members of the University in close touch with the practical department, and it has been of wonderful benefit to both. I thank you most heartily on behalf of myself and the guests on this side of the room, and also on behalf of Sheffield, for the very kind reception you have given us to-night.

SIR H. F. DONALDSON, K.C.B. (Chief Superintendent, Royal Ordnance Factories), who also replied, said: I confess that I feel extremely honoured that my name should be coupled with the toast of "The Guests." I am not here for the first time. My friend, Mr. Balfour, has arbitrarily divided the table in front of us down the middle, and he has claimed one side and has left the other side to me. I do not know whether I am going to trespass on his side; I know that I am going to speak for my own side, because there are others besides myself on this side of the table who have previously been your guests. But there are on this side of the table, and I believe on the other side also, some who have not had the privilege of being your guests before. We of the older generation were prepared to tell them beforehand, if they had asked us, that it was an invitation to accept, because from past experience we of the older generation know that these dinners are full of good cheer and full of

cheeriness. Those of the younger generation know it for themselves now, and I am perfectly sure that both they and we are desirous of showing our appreciation of the hospitality you have extended to us by accepting your next invitation with acclamation! As a guest, I thank you very much for your hospitality. So far, I have not drawn on any fiction at all; if I went further I might perhaps be accused of it. I do not want to be in the position of the schoolboy author, who was invited to write a novel for the school magazine. He began with Chapter I., which the editor of the magazine found was excellent, and said, "Go on with Chapter II." So he went on with Chapter II., which also met with approval. I consider that I have finished my Chapter II. The schoolboy author was invited to start Chapter III., but then he came to grief, because the first sentence of Chapter III. began: "'Hell and damnation,' said the duchess, who previously had taken no part in the conversation." Gentlemen, I want to avoid such a pitfall, and as this is the last speech of the evening, I hasten to couple my personal thanks with those of my portion of your guests, and to resume my seat.

BIRMINGHAM LOCAL SECTION.

A MEETING of the BIRMINGHAM LOCAL SECTION of the INSTITUTE was held on November 14, 1911, when Mr. JOHN CARTLAND, M.Sc., of the University of Birmingham, read a paper on "The Use of Dressed Moulds in Strip Castings," Mr. G. A. BOEDDICKER being in the chair.

The following notes constitute a *résumé* of Mr. Cartland's paper :—

Strip ingots for rolling are always cast in greased moulds prepared by smearing the moulds with heavy oil, and shaking over them a bag containing powdered oak charcoal. The reason for thus preparing the moulds has always been taken to be for the purpose of producing a reducing flame through which to pour the metal; the idea being that contact of the metal with the atmosphere is injurious.

The chief defect of the process is the formation of spilly ingots due to blowholes.

It has been observed that if a draught blows aside the flame (caused by the burning grease) through which the metal is being poured into the mould, the stream of metal exhibits a bright streak of a greenish colour, and in cases where this has occurred the ingots tend to be "spilly," although the formation of "spilly" ingots is very often independent of this phenomenon.

When ingots containing blowholes have been produced as above described, and the part near the gate containing the blowholes has been broken off, the rest of the ingots may be rolled often with good results, though such ingots are never dependable; but the fact that they are not dependable has not been traced to any fundamental defect in the structure, composition, or nature of the metal itself, but is rather due to the possibility of more blowholes existing farther down in the ingot, which has not been broken off in the part which was obviously "spilly."

With increasing percentages of zinc there is, perhaps, less liability of "spilly" ingots being formed, but although experience does not bear this out as by any means an inflexible rule, it is generally found that it is more difficult to get sound ingots with high percentages of copper.

The author found the surface of the undressed mould ingot to be pitted with blowholes, whereas the surface of the dressed mould ingot is not. This is explicable, quite independently of the gases dissolved, by the lubrication afforded by the dressing which assists the air bubbles, entrapped in pouring, to rise.

The dressed mould ingot possesses superior mechanical properties as shown by the rolling tests. The hardness of the two ingots as measured

by the scleroscope is the same, as is also their analyses. The microstructure of the two ingots is nearly the same, the structure of the dressed mould ingot being slightly larger.

Neither of the ingots are seriously "spilly," although both contain some blowholes, which owe their origin to the fact that the solubility of gas is less in the solid than in the liquid metal, and that, therefore, a small quantity of gas is evolved on cooling, which becomes entrapped as blowholes in the solidifying metal. The phenomenon of blowholes (apart from those on the surface in contact with the mould) is independent of the dressing or otherwise of the mould.

The quantity of gas dissolved, together with that in the form of blowholes, is approximately the same in each of the ingots, being about 30 per cent. of the volume of the metal. This is less than the amount found by Guilleman and Delachanel.

As regards the nature of the gases dissolved, results are too erratic to enable it to be stated definitely if there is any difference in the composition of the gases obtained from the two ingots; but if there is any such difference, it is slight, the composition of the gas from both being roughly:—

	Per Cent.
Carbon dioxide	3·5
Oxygen	nil.
Hydrogen	59·0
Carbon monoxide	27·6
Marsh gas	5·60
Nitrogen	4·8

All the results of the research have led the author to conclude that the gases dissolved in the ingots are not the cause of the difference in the mechanical properties.

In a paper on the welding up of blowholes, Dr. J. E. Stead* states that blowholes in steel ingots, the surfaces of which are clean, will weld up on rolling, whereas if the blowholes contain segregated oxide or impurity they will not weld. The author puts forward the suggestion that much the same thing occurs in the case of strip ingots, but in this case the reducing gases through which the metal is poured take the place of the carbon in steel, in reducing oxides which would tend to form a coating on the walls of the blowholes and prevent welding on rolling. This theory has not yet been confirmed by the microstructure owing to the extreme difficulty of detecting zinc oxide or copper oxide in brass.

The obvious advantage, however, resulting from dressing the moulds is the elimination of surface blowholes.

* *Journal of the Iron and Steel Institute*, No. I., 1911, vol. lxxxiii.

A MEETING of the BIRMINGHAM LOCAL SECTION of the INSTITUTE was held on December 12, 1911, when Messrs. MILNS and ANDERSON, of the City of Birmingham Electric Supply Department, read a paper on "The Uses of Electricity in Brass and Copper Rolling-Mills," Mr. G. A. BOEDDICKER being in the chair.

The following notes constitute a *résumé* of Messrs. MILNS and ANDERSON'S paper:—

After a general introduction by Mr. Anderson, Mr. Milns explained the advantages of the use of electricity in rolling-mills, restricting himself, however, entirely to electricity as supplied from a public or private generating station. In comparing this with steam power, he stated that there was a great saving in first cost, that much less space was occupied, and there was a more regular output owing to the overload which a motor could carry and the constant speed at all loads. As a load on a rolling-mill showed very great variations, ranging, for instance, in one case, from 150 horse-power to 550 horse-power, a motor would show a great economy over a steam-engine, as it would have an efficiency of 92 per cent. at 550 horse-power and 85 per cent. at 150 horse-power, results which cannot possibly be obtained by steam plant. Labour and other costs were constant with a steam-engine however loaded, and there was a greater steam consumption per horse-power at low loads than full loads. Another important point was the greater reliability. Steam plant was dependent on the water supply, the boiler (with economiser), superheater, &c., the steam pipes, and the engines; while electric supply from a large central station was absolutely reliable.

He thought the cost of electricity would compare very favourably with the cost of the steam plant, as it was cheaper to produce in one central station 30,000 or 40,000 horse-power than to produce 1000 horse-power at the works. He also advocated the use of electric furnaces, which had the advantage of less floor space, lower first cost, lower working costs, and greater reliability, as they were so easily controlled. For auxiliary plant the use of electricity was an absolute necessity, as it did away with a number of small engines, a great length of steam pipes and shafting, and was strongly to be recommended for wire drawing, slitting, shearing, sawing, &c. In many wire mills electric welding took the place of brazing, and gave greater efficiency at less cost. He need not mention electric lighting, because it was acknowledged that with metallic filament lamps, electric light was more efficient and cheaper than other light.

The paper was illustrated with a number of diagrams and photographs of steam plant, electric plant, electric furnaces, and a flexible coupling which was strongly recommended.

DISCUSSION.

Mr. DU PASQUIER expressed himself in agreement with the general conclusions of the authors, and thought it to be essential to purchase the

power from a large supply company, which would give practical freedom from breakdown.

Mr. W. H. A. ROBERTSON expressed surprise that the authors condemned steam-engines so generally, for, after all, they used steam-engines themselves for producing their electricity. He noticed in America and Germany belt drives were generally used, but he would prefer a rope drive as more flexible. He thought the flexible couplings were well worth their high cost.

Mr. T. VAUGHAN HUGHES was surprised that the authors had not taken into account the cost of the generating plant; whether laid down by a corporation or private firm, the cost would have to be paid by the consumer of the current.

Mr. A. SPITTLE thought the price mentioned in the paper of 1d. per unit would not compare favourably with steam for the driving of roller mills. When current could be supplied at 0·4d. or 0·5d. per unit the electrification of roller-mills would be worth considering, anyhow for heavy mills, while of course it was advantageous for auxiliary machinery. He thought the efficiency of motors at small loads would drop as much as the efficiency of the steam-engine.

Mr. J. R. MACINTOSH, on the other hand, thought at low loads the efficiency of a steam-engine was much below that of an electric motor under the same conditions. He mentioned also the Ilgner system of driving reversing mills for rolling heavy copper plates, of which several plants had been installed in this country.

Mr. ROSCHER (visitor) said he did not think that any works in Birmingham would adopt steam for a new mill, but he thought a private power station could supply electricity at a lower rate than it could be purchased, though the indirect advantages of buying from a large station were considerable. He specially mentioned the great advantage that a motor could be safely overloaded to a very large extent without damage.

Mr. J. W. EARLE said that, as a result of experiments, he would not instal any more electric drives for heavy mills while the cost—1d. per unit—was so high.

Mr. FOSTER (visitor) agreed with the authors generally, and thought it more advantageous to purchase current than to generate one's own. He considered the induction type of furnace as good as a resistance furnace, particularly as regards the circulation of the metal.

Mr. MILNS, replying to the criticisms, defended his statements, and he added that, in his opinion, for sizes above 100 horse-power high tension motors were preferable, and if properly installed would be quite safe.

A MEETING of the BIRMINGHAM LOCAL SECTION of the INSTITUTE was held on February 6, 1912, when Mr. L. ARCHBUTT, F.I.C., presented the following two papers: "The Influence of Certain Elements on the Forging Properties of Copper at Red Heat," and "Note on a Curious Change in the Microstructure of White Metal Produced by Traces of Zinc," Mr. G. A. BOEDDICKER being in the chair.

THE INFLUENCE OF CERTAIN ELEMENTS ON THE FORGING PROPERTIES OF COPPER AT RED HEAT.

Mr. Archbutt said that Mr. F. Johnson's* valuable paper on "The Effect of Silver, Bismuth, and Aluminium upon the Mechanical Properties of 'tough-pitch' Copper containing Arsenic," and the excellent discussion and correspondence to which it gave rise, were of special interest to him, because he found, several years ago, that the commercial refined copper used for locomotive fireboxes and stays frequently contained much more bismuth than the 0.005 per cent. which found its way into engineering specifications as the highest permissible limit for this element after the late Sir William Roberts-Austen had drawn attention to the evil effects of bismuth on copper in the second report to the Alloys Research Committee of the Institution of Mechanical Engineers (1893). About the time referred to, he made many complete analyses of copper firebox plates and staybolt metal, and seldom found so little bismuth as 0.005 per cent. Thus, in 100 firebox plates from various makers analysed during the years 1891 to 1902 inclusive, he found percentages of bismuth ranging from nil to 0.046 per cent., the average being 0.015 per cent. In that average he did not include two plates in which the extraordinary proportions of 0.050 per cent. and 0.067 per cent. of bismuth were found. These plates gave the following further results on analysis:—

	No. 1. Per Cent.	No. 2. Per Cent.
Copper	98.92	99.17
Arsenic	0.664	0.630
Antimony	0.045	0.033
Lead	nil.	nil.
Bismuth	0.050	0.067
Oxygen	0.062	0.091
	<hr/> 99.741	<hr/> 99.991

He was assured that No. 1 of these plates flanged at a red heat without the slightest indication of cracking or lamination. Both plates were put into a stationary loco type boiler, and, so far as he was able to ascertain, gave good results. He had also analyses of two other plates containing nearly as much bismuth which were put into some tank engines, but the history of those he was quite unable to trace. He might also remind his

* *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 163 *et seq.*

hearers that at the end of Sir William Roberts-Austen's report, an analysis was given of a firebox plate taken from a locomotive of the Metropolitan Railway, which had been running for twenty and a half years and had done a mileage of 500,000, and which contained 0.036 per cent. of bismuth with a nearly equal amount of antimony, 0.304 per cent. of nickel, and 0.373 per cent. of arsenic, together with the extraordinary proportion of 0.409 per cent. of lead. Also, among Mr. Dean's analyses, there was a firebox plate containing 0.037 per cent. of bismuth and 0.122 per cent. of lead, with 0.191 per cent. of arsenic and 0.136 per cent. of oxygen, which had done 427,296 miles, one with 0.043 per cent. of bismuth, 0.081 per cent. of lead, 0.811 per cent. of arsenic, and 0.045 of oxygen, which had done 493,994 miles, and another with 0.063 per cent. of bismuth and 0.381 per cent. of lead, with 0.077 per cent. of oxygen and no arsenic, which had done 223,801 miles; this last analysis must have been incorrectly reported.

There being no possible doubt from Arnold and Jefferson's experiments (1896), as well as those of Sir William Roberts-Austen, as to the extremely injurious effect of bismuth on pure copper, the conclusion seemed inevitable that the foreign elements, or some of them, contained in commercial tough-pitch copper must neutralise in some way, and to some extent, the injurious effects of the bismuth. He mentioned the matter to Mr. E. A. Lewis, which led him to make the experiments recorded in a paper published in *Engineering*,* to which Mr. Johnson had referred in his paper. Some time later, in September 1904, Mr. Lewis happened to be working in his (Mr. Archbutt's) laboratory, and they prepared together a series of small ingots of electro-copper to which bismuth, arsenic, antimony, and cuprous oxide were added in variable proportions, and these were subsequently hammered at a red heat and the results observed. (See Appendix.) The experiments were very rough, just such as he had time to make in the course of his very varied general work, and not intended for publication. But having been asked by the honorary secretary of the Birmingham Local Section to read a paper before the Section, he thought those bars might perhaps be of sufficient interest to bring before the Section as a contribution to the *historical introduction* of Mr. Johnson's paper. He would now describe the specimens and pass them round for inspection. Each bar had a label attached showing the percentage of foreign element added. In two cases only the results had been checked by analyses, and showed a good agreement.

The bars containing antimony fully confirmed the results obtained by Mr. F. Johnson and Mr. T. Johnson, that that element was not nearly so injurious as bismuth, and in very small amounts had much the same effect as arsenic. The bars 20, 26, and 28 lent some support to the view that antimony was less harmful in pure copper than in copper containing arsenic and oxygen, but perhaps some one who knew could say more about that? Anyway, the statement attributed to a well-known copper manufacturer, that one ten-thousandth of antimony would make good copper into the worst conceivable seemed to be quite an error.

* December 4, 1903, p. 953.

In bringing the subject forward for discussion, Mr. Archbutt said he did not wish to be misunderstood. He was not there as an apologist for bismuth in copper by any means, and he fully accepted Mr. F. Johnson's well considered conclusions as to the limits which ought to be placed upon its presence even in refined tough-pitch copper. The specimens were exhibited merely as a matter of interest, and as affording another instance of the fact that the injurious effect of bismuth could be to some extent neutralised by the presence of certain other elements.

APPENDIX.

EXPERIMENTS WITH ELECTROLYTIC COPPER TO DETERMINE THE EFFECT OF IMPURITIES.

The copper was melted under charcoal, the element added, and then cast into an iron mould 3 inches deep by 1 inch diameter. Oxygen was added as cuprous oxide, the other elements as elements. The ingots were heated in a muffle to a red heat, and hammered until just below visible redness. In most cases they were reheated and hammered again, and this was repeated as many times as necessary.

Bismuth Series.

Bar No.	Elements added, per Cent.			Result of Test.
	Bismuth.	Arsenic.	Oxygen.	
1.	...	...	...	Forged well and did not crack.
3.	0·2	...	...	Cracked at first hammering, and broke to powder at black heat.
4.	0·05	...	...	Cracked in half.
5.	0·05	...	0·15	Cracked through, but stood more forging than No. 4.
6.	0·05	...	0·20	Slight cracks at edges. The cracks extended on repeated hammering, but not sufficiently to prevent it being forged. On bending at red heat it cracked more.
9.	...	0·4	...	Forged well and did not crack.
11.	0·05	0·4	...	Cracked at corner. On reheating forged well, without cracking further. First cracks may have been due to hammering at too high a temperature.
12.	0·05	0·3	...	Slight cracks at edges. Forged well and doubled up at red heat with only a few small cracks at corners.
7.	0·05	0·01	0·1	Cracked through; but stood a lot more forging than No. 4.
8.	0·05	0·2	0·1	Forged and bent double without cracking at red heat.

Lead Series.

Bar No.	Elements added, per Cent.			Result of Test.
	Lead.	Arsenic.	Oxygen.	
14.	0.2	...	...	Forged easily without cracking.
17.	0.2	...	...	Forged without cracking, and bent double at red heat.
15.	0.05	...	...
16.	0.05	...	0.1	Cracked at one corner. Forged well without further cracking, and bent double at red heat. First cracks perhaps due to being hammered at too high a temperature.
18.	0.1	0.4	...	

Antimony Series.

Bar No.	Elements added, per Cent.				Result of Test.
	Antimony.	Arsenic.	Oxygen.	Lead.	
20.	0.1	...	...	...	Forged easily without cracking, and bent double at red heat. After annealing by quenching in water from dull red heat, bent double cold.
22.	0.1	...	...	0.1	
24.	0.05	...	0.1	...	
26.	0.1	0.4	...	...	Cracked slightly at corners. Very hard. Forged well without further cracking, and doubled up at red heat. After annealing, doubled up cold.
28.	0.2	0.2	0.2	...	Cracked slightly at corners. Harder than 26. Forged as well as 26, and doubled up hot and cold.

Oxygen Series.

Bar No.	Element added, per Cent.		Result of Test.
	Oxygen.		
31.	0.1		Forged well. Harder to hammer than No. 14.
33.	0.2		Forged well. Much harder to hammer than No. 14.
34.	0.25		Very tough. Forged and bent double at red heat without a crack. Doubled up cold.

NOTE ON A CURIOUS CHANGE IN THE MICRO-STRUCTURE OF WHITE METAL PRODUCED BY TRACES OF ZINC.

THE white metal used on the Midland Railway has the composition :—

	Per Cent.
Tin	84·2
Antimony	10·5
Copper	5·3
Total	100·0

Ingots of that metal usually had a reddish tinge, but sometimes the colour was dead white. He analysed one of those white ingots, which was composed of old remelted metal, and found the composition to be :—

	Per Cent.
Tin	81·02
Antimony	11·05
Copper	7·22
Lead	1·30
Zinc	0·032
Iron	0·034
Total	100·656

A section of that metal when polished and etched was found to have a peculiar structure, the usual SbSn cubes having a ruptured appearance. An experiment was made by adding 0·1 per cent. of zinc to another ingot of old metal. It was found that this changed the colour of the ingot, and had the same effect upon the microstructure, but more marked. In that case the cubes showed a tendency to coalesce, forming star-shaped groups, and showing the same tendency to disruption.

Subsequently four small ingots were cast in the laboratory, one composed of the pure metals in the correct proportions, and the other three the same metals with the addition of 0·2, 0·1, and 0·01 per cent. zinc respectively. The structure of those four alloys and also of the two previously mentioned, under a magnification of 100 diameters, was shown in Plate XXII. In the alloy containing 0·2 per cent. of zinc, the SbSn constituent appeared to exist partly in the form of small grains scattered throughout the alloy.

DISCUSSION.

A discussion followed the reading of Mr. Archbutt's papers, in the course of which

Mr. BOEDDICKER said that the author's papers both made clear the necessity for accurately determining the impurities in metals, as very minute traces of such impurities had in many cases so great an effect.

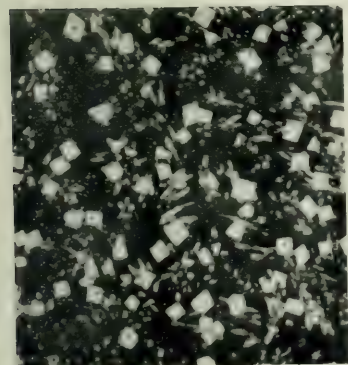


FIG. 1. New Metal. No Zinc.
Magnified 100 diameters.

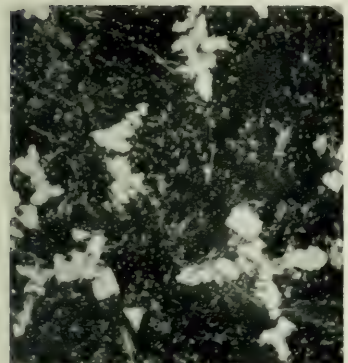


FIG. 2. New Metal. 0.2 per cent. Zinc.
Magnified 100 diameters.

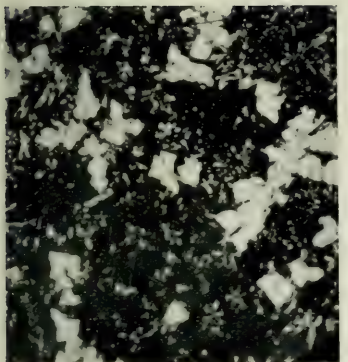


FIG. 3. New Metal. 0.1 per cent. Zinc.
Magnified 100 diameters.



FIG. 4. Old Metal. 0.1 per cent. Zinc.
Magnified 100 diameters.



FIG. 5. Old Metal. 0.032 per cent. Zinc.
Magnified 100 diameters.



FIG. 6. New Metal. 0.01 per cent. Zinc.
Magnified 100 diameters.

EFFECT OF ZINC ON MICROSTRUCTURE OF WHITE METAL.

(All figures slightly reduced in reproduction.)

Mr. O. F. HUDSON said he had seen similar microstructures in faulty white metal to those shown by Mr. Archbutt, but he had been unable to account for the peculiar grouping of the antimony-tin alloy.

Mr. J. W. EARLE considered the papers proved the necessity of using pure metals in manufacture. He was interested to notice how one element nullified the result of another when both were present as impurities. He expressed surprise that lead should not have a bad effect on the forging qualities of copper.

Mr. A. SPITTLE thought the paper on copper showed the fallacy of specifications requiring bismuth in copper to be below 0.005 per cent., for evidently that figure could be safely exceeded, and it was putting copper refiners to a needless trouble.

Mr. T. VAUGHAN HUGHES asked the author if the percentages of added impurities in the copper were the quantities actually introduced, or were they the result of analyses. He thought it risky to assume that those quantities actually existed in the metal after it had been cast. He thought it was also important to know in what form such impurities existed in the metal, whether they were free, or formed alloys or oxides.

Mr. R. M. SHEPPARD asked the author if he had estimated the oxygen in the pure electrolytic copper, or was it absolutely free from oxygen? He had found that in dealing with these pure coppers it was advisable to know the quantity of oxygen present even when it was below 0.02 per cent., as it made a considerable difference in its working properties.

Mr. L. J. MEYRICK said that he did not consider the forging tests a satisfactory test of the quality of the copper. For instance, the sample containing 0.25 per cent. oxygen had forged well, but he did not think it would make a very satisfactory tube.

Mr. F. C. LANTSBERRY inquired why Mr. Archbutt had assumed that it was the minute quantity of zinc that had produced the peculiar microstructure in the white metal. Why should it not be the greater quantities of lead or iron which analysis had shown existed?

Mr. C. H. BARWELL thought the paper on copper proved that bismuth had a bad effect. This was in agreement with his own experience, and he believed it to be a recognised fact all over the world.

Mr. L. ARCHBUTT, in reply, thanked the speakers for their remarks. He said he did not wish to give the impression that bismuth in copper was harmless, but he thought the reports of effects of minute traces on tough-pitch copper were exaggerated, and that small quantities could exist without any very bad effect on the hot forging qualities.

The quantities given for the impurities were the quantities introduced

into the metal before casting, but some of the samples had been analysed, and the analyses proved that approximately the same quantity remained after casting.

He did not claim that the forging quality of the copper was the only point to be considered, and he certainly would not recommend copper tubes being made from castings containing 0.25 per cent. oxygen. The experiments had been made solely with the intention of discovering what effect certain impurities had on the hot forging of copper, and not what impurities could be safely allowed in copper for all purposes.

In reply to Mr. Lantsberry, he might point to Fig. 1, which showed a perfectly normal structure; whilst Figs. 2, 3, and 6, which showed the abnormal structure, were precisely the same metal with the addition only of the small quantity of zinc.

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

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THE PROPERTIES OF METALS AND ALLOYS.

CONTENTS.

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I.—COMMON METALS.

Action of Water on Metals.—The part played by colloids in the corrosion of metals by water and salt solutions is shown by M. Traube-Mengarini* and A. Scala to be an important one. Thus zinc, copper, nickel, and tin, in contact with pure distilled water, gradually yield a colloidal solution, in which minute particles may be detected by the ultra-microscope. Lead yields a colloidal solution of the hydroxide under the same conditions, and in presence of salt solutions a protecting layer of patina is found, but on bringing into contact with pure water again, this patina is at once removed, and lead again goes into colloidal solution. This process is of great importance in connection with the question of the domestic use of lead.

Allotropy of Metals.—The allotropy of tin and antimony was the subject of a lecture by E. Cohen† to the Faraday Society.

Tin.—In 1851 O. L. Erdmann drew attention to a peculiar alteration in structure of some organ pipes in the castle church of Zeitz. Seventeen years later Fritzsche, in St. Petersburg, investigated a profound change in the structure of Banca-tin ingots in store; isolated spots with warty swellings were noticed, also a complete loss of metallic lustre; some blocks had become converted into a grey powder, portions formed lumps of various dimensions of loose cohesion and fibrous texture. Wet or dry heat caused a striking change in this altered tin, the colour

* *Kolloid-Zeitschrift*, 1912, vol. x. p. 113.

† *Transactions of the Faraday Society*, Nov. 1911, Nos. 1 and 2, vol. vii. pp. 122-133.

becoming much lighter. The change from altered to ordinary tin was accompanied by a diminution of volume.

These observations have been confirmed by Cohen,* and the phenomenon proved to be due to an allotropic transformation of the metal. There is a transformation temperature, 18°C ., determined by means of a transition cell. On keeping the temperature of the white tin at 80°C . and raising that of the grey from 0°C . the electromotive force of the cell became zero when the temperature of the grey tin reached 18°C . The enormous increase of volume (as much as 30 per cent.) which accompanies the change from white to grey (altered) tin accounts for the decay of tin objects. The phenomenon has been termed "tin pest." Tin is in a metastable state, except on those warm days when the temperature rises above 18°C .

The "disease" is infectious; contact with altered metal will start the change in ordinary tin, the rate of change being a function of the temperature, increasing as this falls, and reaching a maximum at about -45°C .

Antimony.—By electrolysing a solution of antimony trichloride in hydrochloric acid a substance of metallic lustre is obtained which explodes with some violence on touching with a glass rod, whitish fumes being evolved (G. Gore, 1855).

Cohen has found that solutions of the tribromide and tri-iodide also give this "explosive" antimony, but not the trifluoride. The explosion is due to the allotropic transformation of metastable α to β -antimony, the heat generated (19.6 gramme-calories per gramme) volatilising some antimony halogen compound held in solid solution in the metal. That the halogen compound is in solid solution was proved by extracting "explosive antimony" (safely ground to a powder at -80°C .) with a mixture of alcohol and ether. Not a trace of halogen compound is found in the solvent; if now the powder be heated, antimony halide oozes out, condensing on the cold portions of the vessel. On causing the transformation to take place under ether, no fumes are evolved. β -antimony is proved to be identical with "ordinary" by the fact that the heats of reaction with bromine-carbon disulphide of "exploded" antimony and the same quantity of "ordinary" are identical. We are still confronted with the problem as to why the presence of antimony halide is necessary for the production of the metastable α -antimony.

Aluminium Coinage.—A report to the French Government by M. St. Germain † as to the possibility of using aluminium for coinage, states that, whilst the artistic appearance of coins struck from aluminium and certain of its alloys is all that can be desired, their resistance to wear and chemical corrosion is quite insufficient. The report refers, however, to the use of the bronze containing 90 per cent. of copper and 10 per cent. of aluminium. This is too hard to be struck cold, but it may be struck very satisfactorily at a high temperature in a special press. Alloys con-

* See also *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 310.

† *Journal du Four Electrique*, 1912, vol. xxi. p. 148.

taining from 8.2 to 8.5 per cent. of aluminium may be struck cold, and experiments with these are now proceeding.

Atomised Metals.—Constructional details are given * of an apparatus, known as the "Atomiser," for reducing such metals as zinc and lead to a very fine state of division. By the action of a stream of superheated air or steam, the molten metal as it issues is "formed into a film, leaving the 'atomiser' in the form of a mist." This mist is deposited at the rate of 100 lbs. per hour in the collecting chamber in a pure unoxidised state, its fineness being controlled at will. Such finely divided metal is very reactive chemically, *e.g.* the precipitation of precious metals from cyanide solutions; for further details as to manner of producing this fine "atomised" condition, and other uses to which the process can be put, such as the production of metallic coatings on articles of various descriptions, see Institute Journal.†

Carbon in Nickel.—The solubility of carbon in molten nickel, according to O. Ruff and W. Martin,‡ increases with the temperature up to a maximum at 2100°, when 6.42 per cent. of carbon is present, corresponding with the compound Ni_3C . Above this temperature the solubility is constant. The carbide is unstable, and even rapid quenchings is insufficient to prevent the decomposition into nickel and graphite completely. Rapidly cooled specimens, however, contain a micrographic constituent which is identified with the carbide.

Copper Wire free from Iron.—It is stated by W. Volkmann§ that the assumption usually made, that wire made from electrolytic copper is free from iron, and therefore non-magnetic, is not generally justified. Such wire is required for many galvanometers. In order to obtain diamagnetic copper, it is necessary to deposit the copper from a strongly acid solution, with low current density and continual motion. Such copper is stated to be at present commercially unobtainable.

Deformation of Brass Tubes.—The change of shape of brass tubes under load has been studied by L. Hartmann|| with the aid of the kinematograph, using short tubes compressed in the direction of their length. The figures of folding described are complex, but very regular, and vary for cylindrical, elliptical, or square tubes.

Influence of small quantities of Phosphorus, Manganese, and Tin on Copper.—Experiments by E. Münker¶ show that the addition of small quantities of phosphorus, manganese, or tin to pure electrolytic copper influences the properties of the copper in the same direction,

* *Metallurgical and Chemical Engineering*, March 1912, No. 3, vol. x. pp. 180-182.

† *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. pp. 307-308.

‡ *Metallurgie*, 1912, vol. ix. p. 143.

§ *Elektrochemische Zeitschrift*, 1912, vol. xviii. p. 251.

|| *Comptes Rendus*, 1912, vol. cliv. p. 584.

¶ *Metallurgie*, 1912, vol. ix. p. 185.

raising the hardness and tensile strength, and lowering the ductility, density, and conductivity. Phosphorus has in all cases the greatest effect. Copper containing as much as 1 per cent. of phosphorus may be rolled hot or cold, but the ductility is much reduced by even 0.2 per cent. The alloys containing phosphorus are harder in the cast condition than the corresponding alloys containing manganese or tin, but become softer on annealing, and are then even softer than the manganese alloys.

Notes on the Metallurgy of Wrought Copper.—The principal properties of copper are reviewed by F. Johnson.* The question of oxygen content, effects of mechanical work on the strength and ductility, and its behaviour at high temperatures are then dealt with. For the remarks as to the effects of oxygen, its correct elimination and influence on the casting and subsequent working of the metal, see a previous paper by the author.† Cuprous oxide is said to be easily distinguishable from the sulphide by the fact that hydrofluoric acid etches the former black but leaves the sulphide untouched. Hoffman, Hayden, and Hallowell have proved that the electrical conductivity of copper increases with removal of oxygen, but reaches a maximum whilst the metal is still decidedly under pitch (0.2 per cent. oxygen), and that those traces of sulphur and iron which remain in set copper after the oxidising stage of refining are unaffected by subsequent poling operations.

Hot working of copper should proceed at such a temperature as will allow of a certain amount of recrystallisation or annealing taking place, a fine close-grained structure resulting, rendering the metal more amenable to cold work. The work of Beilby and of Ewing and Rosenhain affords an explanation of the age cracking or secular brittleness of overworked metal.

A photomicrograph of twinning in a sawn casting is shown. The work of Le Chatelier, Roberts-Austen (on deleterious effects of bismuth), F. W. Webb (on firebox stays), and of the Royal Technical Research Commission of Berlin on the behaviour of copper at high temperature ‡ is discussed, and their principal results and conclusions given.

The modern bessemerising process at present used in the smelting of copper reduces the amount of bismuth in the finished metal to a harmless quantity. Keller has shown that 90 per cent. of the bismuth present in the original material is volatilised during the converting operation.

Passivity of Metals.—Experiments by G. Grube,§ with an electrolyte containing potassium ferrocyanide and ferricyanide show that iron, nickel, cobalt, copper, lead, and silver become passive when made the anode in neutral solution, whilst iron, lead, silver, and zinc are also rendered passive in alkaline solution. In all these cases a film of oxide is formed, which is generally visible, but remains invisible in the case of

* *Metallurgical and Chemical Engineering*, August 1911, No. 8, vol. ix. pp. 396-401.

† *Journal of the Institute of Metals*, No. 2, 1910, vol. iv.

‡ See also *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 301. "Influence of Impurities on the Properties of Copper." F. Johnson.

§ *Zeitschrift für Elektrochemie*, 1912, vol. xviii. p. 189.

iron so long as the concentration of the alkali is less than $N/100$. Gold and platinum are unaffected in either neutral or alkaline solution, and nickel, cobalt, and copper in alkaline solution. A coating of the anode with oxygen probably always precedes the formation of a layer of oxide, and is sometimes sufficient in itself to account for the passivity. Peroxides are generally formed, the ferrocyanide acting as an oxygen carrier.

Physical Properties of Aluminium and Magnesium Alloys.—

A. Wilm * gives an account of investigations carried out on alloys of aluminium and magnesium. He found that magnesium, even when in so small a proportion as 0.5 per cent., confers on aluminium the property of hardening on quenching, but that this effect is only manifested after a certain period. Quenching from above a temperature of 500°C ., followed by annealed working, gives the maximum hardness. This quenching effect on aluminium alloys is quite different from that of steels. Thus, the alloy remained soft after quenching, and the hardness only increases after some hours. The change is comparatively rapid when it first begins, but subsequently progresses more slowly.

II.—RARE METALS.

Absorption of Gold by Amalgamated Copper Plates, Cast Iron Retorts, and Amalgam Trays.—The extent to which gold is absorbed by amalgamated copper plates, iron retorts, and amalgam trays during the process of its extraction is studied by G. H. Stanley † and M. T. Murray.

Absorption of Hydrogen by Palladium.—Measurements by S. Valentiner ‡ show that at the low temperature of liquid air the absorptive power of palladium for hydrogen increases rapidly with the pressure when the pressure is low, and the solubility is much greater than corresponds with the square-root law found to hold good for most metals, and for palladium itself at higher temperatures. It appears, therefore, that the phenomenon is one of surface absorption as well as of true solution.

Cerium.—In order to obtain metallic cerium, A. Hirsch § dehydrates the chloride by heating in an atmosphere of hydrogen chloride, and fusing out of contact with air. The fluoride is prepared by precipitating a solution of the chloride with hydrofluoric acid, drying the crystals in a centrifuge, and heating to 200° to remove water. The fluoride, however, corrodes metallic vessels, and the best results are obtained by

* *Revue de Métallurgie*, vol. viii, p. 831; *Métallurgie*, vol. viii, p. 225.

† *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, December 1911, No. 6, vol. xii, pp. 218-222.

‡ *Berichte der deutschen physikalischen Gesellschaft*, 1911, vol. xiii, p. 1003.

§ *Transactions of the American Electrochemical Society*, 1911, vol. xx, p. 57.

electrolysing the chloride in an iron vessel which serves as cathode with a graphite anode. Small quantities of potassium fluoride and barium chloride are added to the electrolyte from time to time. For the decomposition of 1.5 kilogramme of cerous chloride, 200 amperes are required for 3 hours. The metal obtained contains iron, cerium oxide, and cerium carbide. It is purified by amalgamating with mercury, and then heating the amalgam in a magnesia crucible enclosed in an evacuated quartz vessel until the mercury is removed.

The purified cerium (98 per cent.) has the specific gravity 6.92 at 25°, is highly malleable, and can be cut with a knife. It melts at about 635°.

Cerium forms hard and brittle alloys with silver, copper, aluminium, zinc, cadmium, chromium, manganese, and tungsten. The alloys with gold, antimony, and arsenic are soft. Most of the alloys disintegrate gradually, and some of them, especially those with iron, magnesium, and vanadium, give showers of sparks when rubbed with a file.

Electrolytic Amalgamation.—According to W. Heym,* the amalgamation of gold is greatly hastened by the use of an electrolytic method. The finely ground ore or slime is allowed to flow with water through a long trough, the floor of which is a copper plate serving as cathode. The anodes are graphite. A small current, amounting to 5 amperes per square metre of cathode surface, is used, at 5 to 10 volts. A mercury salt is added to the solution, the quantity of mercury required being about the same as in the ordinary amalgamation process. Amalgamation takes place so readily that dirty, greasy, or pyritic gold is quite readily taken up. The addition of sodium salts is desirable, so that some sodium amalgam is formed.

Melting Points of Tantalum and Tungsten.—By using two different methods, W. J. Forsythe† has succeeded in determining the melting points of tantalum and tungsten. In the direct method, tungsten filaments were heated in a special form of graphite tube vacuum furnace, the temperature being read by means of a Holborn-Kurlbaum optical pyrometer, the mean value obtained being 2974°. Tantalum could not be melted in this furnace, owing apparently to combination with carbon. As an indirect method, filaments were heated electrically in a high vacuum in a water-cooled brass vessel with windows, and the curve obtained was extrapolated at lower temperatures, showing the relation between black-body temperature and true temperature. This gave a much higher value for tungsten, namely 3030°, which is probably too high. The value 2798° was obtained for tantalum.

Platinum Laboratory Utensils.—A preliminary report‡ on certain objectionable properties of modern platinum ware has been

* *Elektrochemische Zeitschrift*, 1912, vol. xviii, p. 276.

† *Astrophysical Journal*, 1911, vol. xxxiv, p. 353.

‡ *Metallurgical and Chemical Engineering*, December 1911, No. 12, vol. ix, pp. 649-651.

issued by a committee appointed by the American Chemical Society. There have been studied the content of iridium as affecting loss of weight on ignition; of iron and calcium as causing loss of weight on acid treatment; an unsightly appearance after strong ignition; adherence to triangles; alkalinity after ignition; and blistering and development of cracks.

Radium's Atomic Weight.—Otto Hoenigschmid* has re-determined the atomic weight of radium at the Radium Institute of Vienna. His determinations were made by two independent methods which yielded the same average value, 225.95 (oxygen = 16). The value accepted until now has been 226.4.

Uses of Molybdenum.—Until recently molybdenum was required only for manufacture of chemical preparations, ammonium molybdate, and used as a blue pigment in the manufacture of porcelain and for dyeing purposes. In various compounds it is used for colouring leather and rubber. Ammonium molybdate is used for fireproofing, and as a disinfectant for cloth. Its chief use is in the form of ferro-molybdenum. Molybdenum added to steel is more potent, though similar in its action, than tungsten. Molybdenum steel is used for rifle-barrels, propeller shafts, large guns, wire, and especially high-speed tools (8 to 10 per cent.). When other elements are in correct proportions, a steel is obtained of great hardness, with the peculiar property of retaining its temper to a high degree when heated, enabling extremely heavy cuts to be taken at high speed, the tool often being heated through this hard use to a dull red without impairing its usefulness.†

III.—ALLOYS.

Aluminium Bronzes.—The effect of annealing copper alloys containing 10 to 11 per cent. of aluminium has been examined by A. Portevin and G. Arnou.‡ Quenching from a high temperature produces a martensitic structure. Annealing for ten minutes in a salt bath at 400° increases the hardness and diminishes the elongation and resistance to shock, whilst annealing at 500° has the reverse effect. The separation of the a constituent follows the martensitic arrangement.

Aluminium Bronze Bearings.—Aluminium bronze bearings, § made of an alloy of 92 per cent. aluminium with 8 per cent. copper, have run 50,000 miles on the Northern Railway of France without

* *Engineering*, January 5, 1912, vol. xciii. p. 23.

† *Metallurgical and Chemical Engineering*, February 1912, No. 2, vol. x. pp. 110-111.

‡ *Comptes Rendus*, 1912, vol. cliv. p. 511.

§ *Engineer*, November 10, 1911, vol. cxii. p. 489.

showing any trace of wear. In the case of experiments with this alloy on the Lancashire and Yorkshire Railway considerable difficulty was experienced, owing to its hard and brittle nature, in properly bedding the bearings to the journals, and preventing heating under normal running conditions.

Antimony and Tin.—According to N. S. Konstantinoff and W. A. Smirnoff,* the alloys of antimony and tin form four series of solid solutions, the respective ranges of the two extreme series being 0 to 10 and 90 to 100 atomic per cent., whilst the intermediate series contain the two definite compounds SnSb and Sn_3Sb_2 . The thermal method has been employed, and a study made of the electrical conductivity and its temperature coefficient.

Bearing Bronzes.—It has been found by A. Portevin and Nusbaumer,† that bearing bronzes, containing from 5 to 20 per cent. of tin, with or without the addition of 0.01 to 0.02 per cent. of phosphorus, when tested by pressing on to a revolving disc of hard steel, generally show fairly uniform wear, but occasionally the wear remains practically zero for two or three million revolutions, followed by a sudden loss of material, as much as 0.5 mm. disappearing in a second. The microscopical examination of the specimens giving no wear shows that the α and δ constituents are present in normal proportions, but after annealing for thirty minutes at 600° the α becomes largely twinned, suggesting that the highly resistant surface is in a strained condition. The same effect is observed on hammering a specimen of the bronze, and then annealing. This intermittent behaviour is particularly well seen in a bronze containing 14.42 per cent. of tin and 0.015 per cent. of phosphorus.

Copper Amalgam.—Experiments by A. Guntz and de Greift‡ on the effect of heat and pressure on various amalgams of copper, prepared either by boiling mercury with copper or by electrolysis, show that practically the whole of the mercury may be expelled by sufficient pressure, leaving nearly pure copper, if the amalgam has been heated, but that from 14 to 24 per cent. of copper is retained if the amalgam has been prepared in the cold. The authors explain these results by assuming that the compound CuHg is found at first, but that this dissociates on heating, and that the copper then remains dissolved in the free state on cooling. In accordance with this view, the density of the amalgam prepared electrolytically, which is greater than that calculated by the rule of mixtures, falls to the calculated value after heating to 135° and again cooling.

Diffusion of Solid Metals.—A remarkable example of diffusion of solid metals has been observed by G. Bruni and D. Meneghini.§ A

* *Journal of the Russian Physical and Chemical Society*, 1911, vol. xliii. p. 1201.

† *Comptes Rendus*, 1912, vol. cliv. p. 213.

‡ *Ibid.*, p. 357.

§ *Engineer*, February 9, 1912, vol. cxiii, p. 147.

nickel wire was coated with copper by electrolysis to a thickness such that the two metals were in the same proportions as in the alloy constantan—40 per cent. nickel, 60 per cent. copper. The compound wire thus formed was then maintained at a temperature of about 1000° C. for 157 hours. Its resistance was 0.0260 ohm at the start, and was measured at intervals. It gradually rose to 0.2105 ohm, at which it became practically constant. This indicated that the wire had become converted to constantan, and the fact was proved by chemical analysis.

Heusler Alloys.—It is found by L. O. Grondahl and S. Karrer* that the thermo-electric behaviour of the Heusler alloys is modified by a magnetic field in the same way as the magnetic metals such as iron. Aluminium and zinc are not affected in this way, and the results show that the magnetism of the Heusler alloys is entirely similar to that of iron.

Influence of Increased Temperature on the Strength of certain Metals and Alloys.—A diagram is given† showing the tensile strength of Monel metal, manganese bronze, soft and wrought steel, and copper at temperatures from ordinary to 1250° F. (677° C.).

Inter-metallic Compounds.—A. C. Vournasos‡ has prepared a number of compounds of metals with one another by mixing the molten metals under paraffin at a constant temperature. In many cases a crystalline precipitate of constant composition is thus obtained. For example, by using sodium in excess, the pure compounds Na_3Bi , K_3Bi , Na_2Pb , Na_2Sn are prepared in liquid paraffin of boiling point 375°. The bismuthides of the alkali metals are crystalline leaflets, which oxidise readily in air, even inflaming when quite dry. When potassium bismuthide is heated in hydrogen to 700°, the potassium is volatilised, and bismuth hydride (BiH_3) remains.

Lead, Tin, and Zinc.—An examination of these ternary alloys by M. Levi-Melvano and O. Ceccarelli§ shows that the ternary eutectic point lies at 177°, and corresponds with an alloy containing 71 per cent. tin, 24 per cent. lead, and 5 per cent. zinc. The hardness of the alloys has been measured by Brinell's method.

Magnesium Silicide.—The greatest yield of magnesium silicide is obtained, according to A. Besson|| by using a mixture of two parts of magnesium and one part of quartz, and firing the tightly packed mixture in an iron crucible.

* *Physical Review*, 1911, vol. xxxiii, p. 531.

† *Metallurgical and Chemical Engineering*, March 1912, No. 3, vol. x, p. 160.

‡ *Berichte der deutschen chemischen Gesellschaft*, 1911, vol. xlv, p. 3266.

§ *Gazzetta chimica italiana*, 1911, vol. xli, (2), pp. 269-314.

|| *Comptes Rendus*, 1912, vol. cliv, p. 116.

Monel Metal Castings.—Castings have been made in this metal up to 25,000 lbs. in weight.* This alloy has been found to be as strong as steel and less corrodible than bronze, and takes a finish like pure nickel. Tests under U.S. Navy inspection gave :—

Yield point, pounds per square inch . . .	35,197
Tensile strength, " . . .	72,843
Elongation per cent. (on 2 inches) . . .	28.2
Reduction of area, per cent.	35.6

New Copper Alloy.—Details of a new copper alloy are given,† which has the hardness of steel and great tensile strength. The alloy consists of 11 lbs. chromium melted for one hour with 11 lbs. of aluminium, 242 lbs. of copper being then added, and the entire charge kept at fusing temperature for half-an-hour. 55 lbs. of nickel are next added, and the mixture is heated for another hour, when 44 lbs. of zinc are added. The proportions of copper and chromium may be varied in accordance with the use to which the alloy is to be put, but the order in which the metals are brought to melting temperature, as also the addition of aluminium, must not be changed. The breaking load with this alloy is stated to be 40 tons per square centimetre.

Nickel and Zinc.—The existence of two compounds, NiZn_4 and Ni_2Zn , is maintained by E. Vigouroux and A. Bourbon,‡ the first being a crystalline, non-magnetic powder of specific gravity 7.71. The electrolytic potential curve shows two breaks corresponding with these compounds. Only alloys containing more than 71 per cent. of nickel are magnetic.

Optical Constants of Alloys.—On account of the intimate connection between optical properties and electrical conductivity, J. T. Littleton§ has measured the reflecting power and polarising properties of several series of alloys. In alloys of iron and nickel, nickel and silicon, and iron and manganese the optical properties vary in a strictly linear manner with the composition by volume, the presence of compounds not having any effect. On the other hand, in the copper-aluminium series, there is a distinct break corresponding with the compound CuAl . In the copper-nickel series, the curve has a similar form to that of the electrical conductivity.

Physico-Chemical Study of Mercury-Sodium Alloys.—The constitution of these alloys has been studied by E. Vanstone.|| Cooling curves of a complete series of the alloys were taken, the melts being stirred during cooling. Alloys containing 75–63 per cent. sodium show as many as three and four arrests. The liquidus and portions

* *Metallurgical and Chemical Engineering*, December 1911, No. 12, vol. ix. p. 631.

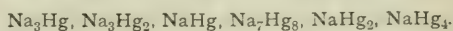
† *Practical Engineer*, November 24, 1911, vol. xliv. p. 663.

‡ *Bulletin de la Société chimique*, 1911, vol. [iv.] ix. p. 873.

§ *Physical Review*, 1911, vol. xxxiii. p. 453.

|| *Transactions of the Faraday Society*, November 1911, vol. vii. (Parts I. and II.), pp. 42–63.

of the solidus thus obtained confirm, to a large extent, the work of Schüller.* Six compounds are shown to be formed having compositions indicated by the following formulæ:—



The compound Na_7Hg_8 is suggested as more probable than Schüller's $\text{Na}_{12}\text{Hg}_{13}$. By casting in glass cylinders closed at one end with a microscope cover glass it has been found possible to study the microstructure of the solid alloys; the photomicrographs show well-defined crystals of certain of the compounds and the eutectic alloy. The results confirm the equilibrium diagram as drawn. Specific volume determinations on both liquid and solid alloys were made. The specific volume-concentration curves for both are smooth, giving no evidence of the existence of compounds. Contraction-concentration curves show discontinuities similar to the liquidus. No connection can be found between molecular volume and valency. Further experiments on electrical conductivity of the alloys are in progress.

Improved methods of making the alloys in a simple manner and quite free from oxide are described, which should lead to their wider application in practice.

Sodium-Potassium Alloys.—An investigation of the alloys of sodium and potassium by G. L. C. M. van R. Hoogendijk van Bleiswijk † shows that only a single compound of the two metals is formed, Na_2K , which breaks up into solid sodium and liquid alloy at 7° . The eutectic point lies at -12.5° .

IV.—PHYSICAL PROPERTIES.

Capillary Constants of Amalgams.—Experiments by G. Meyer ‡ show that, whilst most metals either raise or lower the surface tension of mercury, the alkali metals may be added up to a certain concentration without any effect, but a further addition produces a sudden fall in the surface tension.

Compressibility of Mercury.—A paper by W. C. M. Lewis § discusses the sources of error in the determinations of the compressibility of mercury. It is concluded that the most probable value at 20° is 1.3×10^{-6} per kilogramme per square centimetre.

Effect of Magnetism on Resistance.—The electrical resistance of cadmium, according to C. W. Heaps, || is increased by a magnetic field,

* *Zeitschrift für anorganische Chemie*, 1904, vol. xl. p. 385.

† *Ibid.*, 1912, vol. lxxiv. p. 152.

‡ *Berichte der deutschen physikalischen Gesellschaft*, 1911, vol. xiii. p. 793.

§ *Zeitschrift für physikalische Chemie*, 1912, vol. lxxix. p. 185.

|| *Philosophical Magazine*, 1911, vol. [vi.] xxii. p. 901.

approximately in proportion to the square of the field strength. Nickel and iron increase to a maximum, whilst Heusler's alloy is entirely different, its resistance decreasing with increasing field strength.

Electrical Properties of Aluminium Alloys.—The electrical properties of a large number of alloys of aluminium have been investigated by W. Broniewski,* including the conductivity and its temperature coefficient, the thermo-electric force, and the potential in salt solutions. The research indicates with some degree of certainty the existence of the following intermetallic compounds, most of which are marked by sharp discontinuities in the curves of properties :

AlMg , Al_2Mg_3 , AlAg_3 , Al_2Ag_3 , Al_2Cu_3 , AlCu_2 , AlCu , AlCu_3 , Al_3Fe , Al_3Mn , Al_3Ni .

Electrical Resistance Coefficient of Copper.—J. H. Dellinger† has carried out a series of experiments to ascertain the temperature coefficient of the resistance of copper. Experience has shown that the coefficient varies, and that the conductivity is closely proportional to the temperature coefficient. Thus, annealing results in an increase in the conductivity of drawn wire. It has been found that annealing increases the temperature coefficient in precisely the same proportions, and the results, which are tabulated, show that the measure of the conductivity may be superseded by the temperature coefficient. It is useful in some instances, as in the case of testing turnings from which analyses can be obtained ; in the case of small samples where difficulty is experienced in ascertaining the dimensions, and in wires which have undergone torsion and the apparent conductivity of which is falsified owing to local stresses.

Electrical Resistance of Sodium, Potassium, and their Alloy.—It is shown by E. F. Northrup‡ that the electrical resistance of sodium and potassium increases regularly with the temperature, with a sudden and large increase at the melting point. The alloy containing equal volumes of the two metals has a specific resistance which is three times as great as the mean specific resistance of its components, whilst its temperature coefficient is less than one-third of the mean.

Fusion Points of the Elements.—K. Burgess§ gives a table summarising the most recent determinations of the melting points of elements. This gives the following values :—

* *Annales de Chimie et de Physique*, 1912, vol. [viii.] xxv. p. 5.

† *Revue de Métallurgie*, vol. viii. pp. 833-834 ; *Journal of the Franklin Institute*, vol. clxx. p. 213.

‡ *Transactions of the American Electrochemical Society*, 1911, vol. xx. p. 185.

§ *Journal of the Washington Academy of Sciences*, vol. i. p. 16 ; *Revue de Métallurgie, Extraits*, vol. viii. pp. 727-728.

Manganese	1225 \pm 15
Silicon	1420 \pm 15
Nickel	1450 \pm 10
Cobalt	1490
Chromium	1505 \pm 15
Iron	1520 \pm 15
Vanadium	1730 \pm 30
Titanium	} 2300 (?) 1825 (?) 2500 (?)
Molybdenum	
Tungsten	
Carbon	3000 \pm 100 >3000

Galvanising Wire in Zinc Dust.—According to A. Sang* when iron wire is electrically heated to 500° or 600°, and run through a trough containing zinc-dust mixed with sand, galvanising takes place instantaneously, producing a smooth, lustrous coating.

Interpenetration of Metallic Alloys.—Le Gris† describes the intermolecular penetration of metallic alloys, by which he means the heterogeneous zone obtained between two metals by their superposition in a molten state and when complete mixture has not occurred. When the operation is successful, there will be in the lower portion of the zone one of the metals in a completely pure state, and in the upper part of the zone the other metal similarly pure, while in the intervening space and at different layers there will be in succession all possible alloy compositions of the two metals from zero per cent. to 100 per cent. of any one of them. This method of operating, which has been so far employed for the full and rapid examination of a series of alloys, was described by Le Chatelier a dozen years ago. In carrying out the experiments special precautions have to be employed according to the different metals placed in juxtaposition. The alloys studied were those of copper with aluminium, zinc, antimony, and tin. Sections across the depth of the metal possess the advantage of showing in succession the whole series of alloys, and, if sufficiently thin, enable photographic reproductions to be made on a single plate. The method employed consisted in melting the more fusible metal in a small crucible, introducing a bullet of the less fusible metal and raising the temperature at the same time to the fusion or dissolution point of the latter. In the case of alloys of antimony with lead and tin, a difficulty arises on the one hand owing to the considerable difference between the fusion points of the metals and, on the other hand, owing to the rapid miscibility of antimony in the other metals, the viscosity of which it diminishes. It is necessary in this case to allow a blowpipe flame to impinge on the surfaces of contact of the two metals. Instead of the ordinary crucibles Jena glass tubes were used at one end with a plug of asbestos, while for less fusible metals fused silica tubes or perforated arc lamp carbons were used. A number of photomicrographs are given, showing the conditions of interpenetration, and magnified illustrations of the results of hardness tests along the zones of contact are also given.

* *Transactions of the American Electrochemical Society*, 1911, vol. xx. p. 259.

† *Revue de Métallurgie*, vol. viii. p. 613.

Magnetism of Copper.—According to F. Behnsen* pure electrolytic copper is not permanently magnetisable, and cannot be made so by thermal treatment. The two oxides are also non-magnetisable, but commercial copper oxide becomes permanently magnetic, and yields a magnetic metal on reduction. This must be due to the presence of iron as an impurity.

In induction experiments, pure copper, whatever its thermal treatment, is diamagnetic; both its oxides are paramagnetic.

Magnetism of Nickel and Cobalt and their Alloys.—The magnetic moment of alloys of nickel and cobalt, according to P. Weiss and O. Bloch,† is directly proportional to the percentage of cobalt, if the moment is expressed in gramme-magnetons. These quantities are determined by measuring the magnetisation at saturation down to the temperature of liquid air and extrapolating to absolute zero. At higher temperatures, the law of corresponding magnetic states applies to these alloys.

Magnetism of Vanadium Compounds.—It is found by E. Wedekind and C. Horst‡ that although metallic vanadium is only slightly paramagnetic, some of its compounds are much more strongly magnetic. The oxide VO is more magnetic than manganese or chromium oxide. The sulphide is very weakly magnetic, the oxychloride more strongly so.

Melting Point and Electrical Resistance.—An important physical relation is developed by A. Stein.§ Starting from the fact that the electrical resistance of the metals, with the exception of iron, nickel, lead, and zinc, is proportional to the absolute temperature and therefore to the square of the amplitude of vibration of the atoms, use is made of the fact, previously established, that at the melting point the amplitude of vibration of different metals is proportional to the distance between the atoms—that is, to the cube root of the atomic volume. If v is the atomic volume the square of the amplitude is proportional to $\sqrt[3]{v} T/T_s$, where T_s is the absolute melting point. The relative resistance of different atoms is found by determining the resistance per atomic volume. If σ is the resistance per cubic centimetre this is σ/v . The quotient of these two expressions is

$$\frac{\sigma}{T} \cdot \frac{T_s}{v}$$

The value of this expression is found to be 1.1 for copper, gold, aluminium, magnesium, cadmium, and tin; 2.2 for lead and thallium, and about 6.6 for platinum and palladium. The values for silver, 0.67,

* *Physikalische Zeitschrift*, 1911, vol. xii. p. 1157.

† *Comptes Rendus*, 1911, vol. cliii. p. 941.

‡ *Berichte der deutschen chemischen Gesellschaft*, 1912, vol. xlv. p. 262.

§ *Physikalische Zeitschrift*, 1912, vol. xiii. p. 287.

and zinc, 1.6, are abnormal. The resistance may thus be written

$$\sigma = nC \frac{\nu T}{T_s}$$

where C is a constant which is the same for all metals and n is an integer.

Silver Mirrors.—The properties of silver mirrors have been investigated by V. Kohlschütter and E. Fischmann.* It is well known that the colour, reflecting power, &c., of mirrors deposited on glass from ammoniacal silver solutions vary greatly with the reducing agent employed. The active reducing compound is in all cases an aldehyde. The adsorption of silver hydroxide by glass is an essential factor in the formation of an adherent mirror, and the character of the surface is mainly determined by colloidal substances in solution. It is in this way that traces of copper salts, &c., act, as copper is not found in the mirror, but by retarding the reaction and increasing the quantity of colloidal material copper promotes uniform deposition.

Mirror silver is not an allotropic form of silver, but is silver in a colloidal form. The ultramicroscope shows that it is made up of disperse particles. Its electrical resistance is much higher than that of massive silver, but diminishes with time, owing to partial crystallisation. The influence of dilute acids and halogen salts in increasing the conductivity and dislodging the film from the glass is attributed to the coagulating action of electrolytes on the colloidal metal.

Solubility of Gases in Solid Metals.—Experiments by M. Guichard † show that potassium, zinc, and lead give off small quantities of gas when heated in a vacuum, even after having been fused and allowed to cool, some gas being apparently reabsorbed on cooling. Cadmium parts with the gas more readily. Copper has to be heated many hours in a vacuum in order to deprive it entirely of gas. The gas in commercial copper consists principally of carbon dioxide.

Solubility of Hydrogen in Platinum and Rhodium.—According to A. Sieverts and E. Jurisch, ‡ platinum wire does not absorb more than traces of hydrogen at the ordinary temperature and pressure. The quantity absorbed increases with the temperature, being about 1 cubic centimetre per 100 grammes at 1340°. This is very much less than the absorbing power of nickel or iron. When the platinum is allowed to cool in hydrogen, it again gives up the whole of the dissolved gas. If the temperature is kept constant, the quantity of gas dissolved is proportional to the square root of the pressure. Carbon monoxide and sulphur dioxide are quite insoluble in solid platinum. Rhodium does not

* *Annalen der Chemie*, 1912, vol. ccclxxxvii. p. 86.

† *Bulletin de la Société chimique*, 1912, vol. [iv.] xi. pp. 49, 50.

‡ *Berichte der deutschen chemischen Gesellschaft*, 1912, vol. xlv. p. 221.

dissolve either hydrogen or carbon monoxide, but the commercial powdered rhodium contains a considerable quantity of gases, which are evolved on heating to redness in a vacuum.

Theory of Thermo-electricity.—The theory of the thermo-electric effect in metals is discussed by P. Cermak.* The conclusion is drawn that Avenarius' formula is of little use, and that much better methods of determining the Peltier and Thomson effects are required before the electron theory can be properly tested. At present the agreement between the theoretical and experimental values is not very good.

* *Jahrbuch der Radioaktivität und Elektronik*, 1911, vol. viii. p. 241.

ELECTRO-METALLURGY.

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I.—ELECTRIC FURNACES.

Electric Resistance Furnace with variable length of bath.—A resistance furnace, intended specially for the reduction of ores and the carrying out of reactions between solid materials and liquid slag, is described by F. Thomas.* The principal feature is the possibility of varying the length of the heating space according to the voltage and to the resistance of the materials to be heated. The furnace is a horizontal cylinder, built up of refractory rings, water-cooled and joined by outer rings and bolts. The water-jacketed iron ends carry the carbon electrodes. A modified form is pivoted for pouring, and is completely water-jacketed. The furnace has been used with success for the reduction of briquetted zinc blende by means of iron and iron sulphide.

Electro-Metallurgy of Tin.—It is stated † that the electric furnace may be used with advantage in the reduction of tin ores. A furnace similar to that designed by Harmel for iron ores is used, constructed of magnesite bricks. The temperature is 1400° to 1500°, and the charge usually requires about 14 kilogrammes of anthracite for every 100 kilogrammes of ore, instead of the usual 20 to 25 per cent. The electrodes are hardly consumed. The current at first is 1000 amperes per phase, at 60 volts, but once the reaction has begun this rises to 2500 amperes and 40 volts. After half-an-hour the slag begins to flow, and the success of the reaction may be judged from its appearance.

Laboratory Nickel Furnace.—The troublesome oxidation of nickel wire when used in a resistance furnace is avoided by L. Ubbelohde, ‡ who coats the winding with a mixture of kaolin, alumina,

* *Metallurgie*, 1912, vol. ix. p. 158.

† *Journal du Four Electrique*, 1912, vol. xxi. p. 32.

‡ *Zeitschrift für Elektrochemie*, 1911, vol. xvii. p. 1002.

and asbestos, outside of which is a packing of granulated carbon. The mixture of carbon monoxide and dioxide which is formed protects the nickel wire, and it is only necessary to introduce some additional carbon after several weeks' use.

Small Furnace with Tungsten or Molybdenum Heater.—

According to R. Winne and C. Dantsizen* a crucible furnace may be made by winding a wire of ductile tungsten or molybdenum round an alundum tube, the coil being enclosed in a space through which hydrogen is continuously passed. This furnace may be worked safely up to 1700°. A tube furnace is made by winding an alundum tube with molybdenum ribbon, packed in silica in an iron casing. Hydrogen is passed through the packing during use.

II.—ELECTRIC SMELTING.

Electric Tin Smelting.—Preliminary experiments on the smelting of tin ore by means of an electric furnace, on a laboratory and also on a commercial scale, are described by J. Hårdén.† Owing to patents pending, details of the shaft furnace and of the actual smelting process employed are deferred for a later occasion. A run usually occupied 10 to 12 days, with a starting current of 1000 amperes per phase at 60 volts rising to 2500 amperes at 40 volts representing the working conditions. Metal was tapped half-an-hour after the first charge. Certain reagents were added at regular intervals to the contents of the furnace which successfully prevented the formation of "hard head" by causing the sulphides and arsenides of iron to enter into the slag instead of alloying with the tin, and resulted in metal of about 98 per cent. purity leaving the tap hole of the furnace. By blowing air through this metal its purity was further increased to 99·75 and even more.

Details of a typical week's run are given as follows:—

Ore used: 21,036 lbs. at 57 per cent.	12,003 lbs. metal.
Scrap metal and charge refuse	2,324 „
	<hr/> 14,327 „
Tin produced	14,170 lbs.
Giving a net yield of 98.75 per cent.	
Total number of kilowatt-hours	15,113
To be deducted: for slag treatment (experiment)	678 } kilowatt-
„ „ „ for preparing furnace, &c.	500 } hours.
Total number of kilowatt-hours used for the reduction	13,935
Units per ton	2,220
Electrode consumption	28 lbs. per ton.

The above figures bear out the author's claim that a considerable saving can be effected by electric smelting, and have encouraged him to proceed with the process in a somewhat modified form by which even greater

* *Transactions of the American Electrochemical Society*, 1911, vol. xx, p. 289.

† *Transactions of the American Electrochemical Society*, 1911, vol. xx, p. 285.
 pp. 453-457.

savings may be expected. The experiments were carried out in Cornwall.

Progress of British Columbia Zinc Investigation.—The gist of a report by W. R. Ingalls, consulting engineer to a commission investigating the zinc resources for the Department of Mines, is given.* A large number of experiments in the field of electric smelting have been carried out at McGill University, Montreal, and several types of furnaces tried. Earlier experiments were directed towards a satisfactory process for condensing zinc as molten spelter; the difficulties have so far not been mastered. The work has indicated that in order to achieve any material improvement over ordinary practice of smelting, tedious experiments will be necessary.

Apart from the work in Scandinavia, where two electrothermic zinc smelters using 7000 and 4000 horse-power are now said to be producing spelter from ore on a commercial scale, the electric smelting of zinc ore, in spite of all claims to the contrary, is not only still in the experimental stage, but is in the infancy of that stage.†

III.—ELECTRO-DEPOSITION.

Corrosion of Electro-plated Objects.—Electrolytic corrosion of electro-plated objects has been investigated by W. Landis.‡ The particular inquiry concerned steel nibs which had been copper plated and then covered with gold. The plating seemed to have been done with great care. But the friction of the pen on the paper soon wore off the plating of the point, exposing the steel, when a steel-ink gold couple was formed, and rapid corrosion set in.

Deposition of Copper in presence of Arsenic.—C. Y. Wen and E. F. Kern§ have determined the conditions under which a satisfactory deposition of copper may be obtained from electrolytes in which arsenic has accumulated from impure anodes. Of inorganic materials, sodium chloride and aluminium sulphate give good results in preventing the deposition of arsenic and the formation of dendritic growths. The best results are obtained by adding sodium chloride and gelatin. Peptone, unlike gelatin, causes an increased roughness of the deposits.

Electrolytic Copper and Lead.—Cathode deposits of copper have been examined microscopically by B. Wäser and R. Kühnel,|| and photographs are given of surfaces deposited under different conditions

* *Metallurgical and Chemical Engineering*, November 1911, No. 11, vol. ix. p. 588.

† For previous abstracts dealing with this subject, see the *Journal of the Institute of Metals*, No. 2, 1911, vol. vi. pp. 324-325.

‡ *Engineering*, January 12, 1912, vol. xciii. p. 56.

§ *Transactions of the American Electrochemical Society*, 1911, vol. xx. p. 121.

|| *Elektrochemische Zeitschrift*, 1912, vol. xviii. pp. 151, 211.

of the electrolyte and current density. Similar photographs of lead are given. In this case the formation of distinct crystals is readily observed.

Electro-deposited Nickel.—The causes of peeling of electrolytically deposited nickel have been investigated by K. Engemann,* who finds that when an ammoniacal solution is used as the electrolyte, peeling readily occurs, even if iron is absent. In presence of iron, the peeling is mainly due to the variation in composition of successive layers, the first layers deposited being richest in iron. At higher temperatures, the composition of successive layers becomes more nearly equal. The deposits from solutions of nickel sulphate are more elastic than those from the chloride, whilst the elasticity is also increased by the addition of sodium salts.

Electrolytic Refining at the United States Mint, San Francisco.—An account of the methods and apparatus employed in December 1909 is given by Edward B. Durham.† The refining is carried out in three stages for the deposition of silver, gold, and copper respectively.

Silver Process.—Crude silver bullion and gold bullion too low in gold to be made up into gold anodes are melted together to give an alloy as near as possible to the composition:—

Silver	.	.	.	.	.	.	.	600	fine
Gold	.	.	.	.	.	.	.	300	„
Base metals	.	.	.	.	.	.	.	100	„

and cast into anodes $8\frac{3}{4}$ inches by $3\frac{1}{4}$ inches by $\frac{3}{8}$ inch. The anodes are suspended from the conductors by C shaped hooks of gold which pass through holes in the tops of the anodes. The anodes are immersed to their full depth in the electrolyte, which contains 3 per cent. of silver as silver nitrate, 1.5 to 2.5 per cent. of free nitric acid, and a little glue, added for the purpose of toughening the deposit of silver on the cathode. The cathodes are sheets of fine silver 0.051 inch thick and 4 inches wide. They are immersed to a depth of $8\frac{1}{2}$ inches, and bent over at the top so as to hang on the conductors. There are 18 cells of brown earthenware 39 inches long, 19 inches wide, and 12 inches deep in series, each cell having 40 cathodes. Direct current of 15 volts is used with a current density of 8.3 amperes per square foot of cathode surface, or a total current per cell of 141 amperes. The solution is agitated by glass propellers, and the products dried by centrifugal machines. The products are pure silver, removed daily from the cathodes, and crude or black gold with 10 per cent. of silver and 1 per cent. of base metals, the copper with other base metals remaining in solution. The crude gold after drying is melted and cast into anodes for the gold process. In addition to the 18 vertical silver

* *Zeitschrift für Elektrochemie*, 1911, vol. xvii, p. 910.

† *Mines and Minerals*, 1912, vol. xxxii, pp. 361-367. Reprint of paper read at the October 1911 Meeting of the American Institute of Mining Engineers.

cells there are two sets of 3 horizontal silver cells, the anodes of which consist of the cores of the anodes, and the slime from the bottoms of the vertical cells, and the silver reduced from the silver chloride slime from the gold cells. These loose anodes are contained in wooden trays covered with five layers of 7 oz. duck. The cathodes, on which metallic silver is deposited, are graphite plates on the bottoms of the cells. The electrolyte is the same as for the vertical cells. The 3 cells in each set are in series, and a current of 50 amperes is used (14.3 amperes per square foot of cathode surface) at 5 volts per cell. Black gold is left in the trays, and is dried and melted for gold anodes.

Gold Process.—The anodes, which are of the same size as the silver anodes, have approximately the following composition:—Gold 875, silver 100–125, and a small amount of base metals. The cathodes are strips of pure gold 4 inches wide and 0.012 inch thick. They are bent over at the top to hang on the conductors, and are immersed to a depth of 6 inches. Their original weight is 4.5 ounces, and they are allowed to remain till they weigh 160 ounces, when they are removed and form the anodes of a second set of cells. By this means the final product is 999.7 fine. The electrolyte is a solution gold chloride with 10–12 per cent. of free hydrochloric acid, and contains in the first set of cells 70 grammes of gold per litre, and in the second set 60 grammes of gold per litre. The cells, 16 inches long, $11\frac{1}{2}$ inches wide, and 12 inches deep, are made of porcelain, and are arranged in two sets each of 14 cells in series. There are 8 anodes and 8 cathodes in each cell, and direct current of 15 volts is used in each set of cells, the current density being 90 amperes per square foot of cathode surface. The products are cathode gold, 990.7 in the first set of cells, and 999.7 in the second set, silver chloride slime containing gold resulting from the decomposition of the electrolyte. Copper and other base metals, together with traces of platinum, &c., are retained in solution. The silver slime is reduced with zinc.

Copper Process.—Copper is used to recover silver from various solutions and wash waters, and is subsequently precipitated on scrap iron. The cement copper is melted, cast into anodes, and refined electrolytically in the usual way. The small quantities of metals of the platinum group are precipitated with the copper on scrap iron, and, together with a little gold and silver, remain as slime in the cells. This slime is collected, melted, and cast into bars which are stored for separate refining for recovery of platinum metals.

Refining of Silver and Gold Alloys.—The electrolytic treatment of an alloy of gold and silver, such as is obtained from the Pattinson and Parkes processes, from the treatment of silver-gold alloys and anode sludge, is discussed by E. F. Kern.* The parting of doré bullion, carrying over 75 per cent. silver, with sulphuric acid and also electrolytically, is described.

* *Metallurgical and Chemical Engineering*, September 1911, No. 9, vol. ix, pp. 443–447.

Treatment of the Anode Sludge in Electrolytic Refineries.

—E. F. Kern* deals with the composition, preparation, and the various methods of treatment for the recovery of precious and other metals from anode sludges formed during the electrolytic refining of metals.

* *Metallurgical and Chemical Engineering*, August 1911, No. 8, vol. ix, pp. 417-420.

ANALYSIS, TESTING, AND PYROMETRY.

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I.—ANALYSIS.

Analysis of Manganese Bronze.—Various improvements are described by J. R. Huber * as a result of further experience in the method of analysis of manganese bronze previously described by H. B. Swan.† Five grammes of the bronze are dissolved in 50 per cent. nitric acid, and the solution, after the removal of tin and lead, is made up to 500 cubic centimetres. In two quantities of 100 cubic centimetres the copper is determined by electrolysis, and in the copper free liquid from one the iron is estimated by titration with permanganate (Blair) and in the other the manganese by sodium bismuthate.

The copper is then removed from two other portions of 100 cubic centimetres by electrolysis without the addition of nitric acid, and in the resulting liquid the zinc is separated from the aluminium, manganese, and iron by precipitation with hydrogen sulphide in the presence of hydrochloric acid and ammonium sulphocyanide, as suggested by Kemimerer,‡ the iron being previously reduced by means of sulphurous acid. The authors claim that they hereby obtain the zinc in granular form entirely free from iron. The aluminium is estimated in the filtrate as aluminium phosphate.

Assay of Platinum Alloys.—According to Trenkner § the error in assaying alloys of gold and platinum, which is considered by the Paris Mint to amount to 1 per cent., may be very greatly lessened by the following procedure. The alloy is subjected to a preliminary assay, and is then alloyed with sufficient silver to make the ratio of silver to gold and platinum 10 : 1. The button is then cupelled in the usual way, the loss of silver being determined by means of a parallel check assay. Lead

* *Metallurgical and Chemical Engineering*, August 1911, No. 8, vol. ix. p. 403.

† *Journal of the Institute of Metals*, No. 2, 1910, vol. iv.

‡ *Journal of Industrial and Engineering Chemistry*, September 1910.

§ *Metallurgie*, 1912, vol. ix. p. 103.

is not retained by the bead. Parting is effected by means of 25 cubic centimetres of concentrated sulphuric acid, using a parting flask and not allowing the acid to boil. The bead, which must not have been flattened, retains its shape and contains very little silver. After dissolving in *aqua regia*, the gold is precipitated by adding 15 cubic centimetres of hydrochloric acid and 1 gramme of hydrazine hydrochloride and allowing it to stand an hour. The gold precipitate is collected, washed, ignited, and weighed. Platinum is precipitated from the filtrate by ammonia and ignited. The error is found, by a number of test assays, not to exceed 0.5 part per 1000. The method may be applied to ores.

Copper and Brass Analysis.—E. A. Lewis* deals with the limits of accuracy in the estimation of copper. A table is given of the probable limits of accuracy in the usual estimations made in the analysis of brass and similar alloys, and it is pointed out that it is misleading to report analyses to two places of decimals when the methods used are not trustworthy beyond the first place. In coarse borings, &c., the error may reach 1 per cent. even with careful sampling. The author refers to the desirability of standard methods of analysis, in view of the divergent results sometimes obtained by equally skilled analysts using different methods.

Copper and Silver.—The method of determining the end-point of a titration by measurements of electrical conductivity has been employed by P. Dutoit and G. von Weisse.† In the case of copper, precipitation by a solution of crystallised sodium sulphide is found to give the best results, the change of potential being very sharp. The sulphide solution must be standardised by copper solution of about the same concentration as that to be used, and must not be weaker than $N/50$ on account of the liability to oxidation. The solutions used must be slightly acid with acetic acid. Copper and silver may be estimated accurately in solutions containing 20 milligrammes per litre, and much smaller quantities may be estimated. Neutral salts are without effect.

Determination of Gold and Silver in Copper.—Experiments are described by E. F. Kern‡ and A. A. Heimrod, for the purpose of evolving reliable and standard methods of determining gold and silver in copper.

Determination of Gold.—Silver chloride precipitated with the gold proved a better collecting agent than sulphate of lead. Standard alloys were prepared containing up to 100 ozs. of gold per ton, and the method finally adopted, which according to the published figures gives very concordant results, was as follows:—

The alloy is attacked with somewhat diluted nitric acid without any addition of hydrochloric acid. Concentrated sulphuric acid is then added

* *Journal of the Society of Chemical Industry*, 1912, vol. xxxi. p. 96.

† *Journal de Chimie physique*, 1911, vol. ix. p. 608.

‡ *Metallurgical and Chemical Engineering*, October 1911, No. 10, vol. ix. pp. 496-499.

and the whole evaporated until there remains a mass of copper sulphate crystals, with part of the water of crystallisation driven off. The mass is taken up with water, ferrous sulphate added to precipitate any gold in solution, followed by sodium chloride and sufficient silver nitrate to make a bead weighing about eight times that of the gold present.

The resulting precipitate of silver chloride carrying the gold is scorified in the usual manner on a glazed scorifier. The resulting lead button is cupelled on a medium hard bone ash cupel, and the gold-silver bead parted with nitric acid.

Determination of Silver.—Concordant results were obtained by the following method:—

The alloy is dissolved in nitric acid, the solution evaporated until crystals of copper nitrate separate, taken up with cold water and the silver precipitated with ammonium sulphocyanate. Precipitate and filter paper are digested with concentrated nitric acid until the whole of the precipitate has dissolved. The solution is then evaporated to a small bulk to ensure removal of all oxides of nitrogen, the sulphuric acid precipitated with barium nitrate, and the silver titrated with ammonium sulphocyanate, using ferric alum as indicator.

Electrolytic Determination of Lead.—Details of an electrolytic method for the “rapid and accurate determination of lead in large and small amounts,” precautions necessary to prevent interference of other metals, and a brief description of the stationary electrodes are given by E. List.* The deposition takes place in the presence of nitric acid and ammonium nitrate, the electrolyte being kept warm. Complete deposition apparently takes two hours. The deposit can be obtained in a firm adherent form. Bismuth will contaminate the deposit even in the presence of a large excess of nitric acid, imparting a light blue colour to it. Arsenic and tellurium effectually prevent the deposition taking place.

Electrolytic Determination of Lead in large and small amounts, using a Gauze Cylinder Anode.—Conditions that have been found necessary to obtain a satisfactory deposition of lead on a rotating gauze anode are given by B. Woiciechowski.† The method as used for babbitt metals having lead as a base is as follows:—

Tin and antimony are separated by means of sodium sulphide; the sulphides of copper and lead are dissolved in nitric acid, the solution is heated to boiling and electrolysed with a current of 3 amperes, rising to 5 amperes after the first two or three minutes and continued for 20 to 30 minutes. The volume of solution is from 150 to 200 cubic centimetres, nitric acid in quantity equivalent to 45 cubic centimetres of concentrated acid per 150 cubic centimetres of solution being present. This amount of acid may be reduced if copper is present in large amount and lead does not exceed 10 to 12 per cent.

* *Metallurgical and Chemical Engineering*, March 1912, No. 3, vol. x. p. 135.

† *Ibid.*, February 1912, No. 2, vol. x. p. 108.

The deposit of peroxide must be dried at 230° C. for 20 to 30 minutes according to the quantity, and is obtained in a firm adherent condition.

A magnetic rotating apparatus called the Frary Solenoid (see "Electro-Analysis," Smith, or "Technical Analysis of Brass," Price and Meade), has proved most satisfactory for estimating lead in large quantities, amounts of 0.005 gramme to 2.00 grammes being handled without any difficulty.

Estimation of Nickel in German Silver.—F. Ibbotson * recommends that 0.5 gramme of the alloy be dissolved in 10 cubic centimetres of nitric acid, specific gravity 1.2, and diluted to 400 cubic centimetres. After adding 0.3 gramme of tartaric acid, an excess of ammonia is added, and the nickel is precipitated at 50° with an excess of dimethylglyoxime. The precipitate must be redissolved in nitric acid, and again precipitated, to remove copper.

Notes on Technical Analysis.—A method for the analysis of ores containing molybdenum and tungsten is given by R. S. Davis.† One gramme of the ground ore, after treatment with *aqua regia*, is evaporated to fumes with sulphuric acid, and the soluble residue filtered into a pressure bottle. Precipitate molybdenum in the filtrate by passing sulphuretted hydrogen for 15 minutes, then close the bottle and heat for 20 minutes in boiling water. Dissolve the sulphide in nitric acid, evaporate and heat to remove all sulphuric acid. Dissolve resulting oxide in ammonia and precipitate and weigh molybdenum as lead molybdate. The filtrate from the molybdenum will be green or blue if vanadium is present. Boil to remove sulphuretted hydrogen, oxidise with excess of permanganate, boiling for 5 minutes. Add ferrous ammonium sulphate to clear the solution, and boil. Cool, add permanganate until a pink colour persists, add then ferrous ammonium sulphate in slight excess. Titrate back with permanganate until no blue colour is shown by the ferricyanide indicator, read the burette, and then add permanganate to a pink colour. The iron value of the permanganate $\times 0.916 =$ vanadium.

Tungsten and silicon are best determined on a fresh sample. One gramme of ore is treated with hydrochloric acid and evaporated to dryness. Take up with dilute hydrochloric acid, filter and wash free from lead with hot hydrochloric acid by decantation. Dissolve the oxide of tungsten in ammonia and ammonium chloride, evaporate to dryness and ignite at a dull red heat. Determine silica in the residue by volatilisation with hydrofluoric acid.

Platinum Assay.—The usual method of assaying platinum may be improved, according to A. Steinmann,‡ by using as the parting acid a mixture of 100 volumes concentrated sulphuric acid and 22 volumes

* *Chemical News*, 1911, vol. civ, p. 224.

† *Metallurgical and Chemical Engineering*, September 1911, No. 9, vol. ix, pp. 458–459.

‡ *Journal Suisse de Chimie et Pharmacie*, 1911, No. 32.

water, and heating to 240°. Hardly any platinum is then dissolved. If some copper is added before cupellation, lead and silver are not retained by the button.

Purity of Commercially Pure Metals.—F. Mylius* has made a study of the quantity of impurities in the best obtainable commercial samples of metal, those supplied by Kahlbaum. The following metals are readily obtainable with less than 0.01 per cent. of impurity: gold, silver, platinum, mercury, copper, tin, lead, cadmium, and zinc.

In analysis of this kind, the most difficult operation is the removal of the bulk of the principal metal. Precipitation must be avoided, as the amorphous precipitates carry down small quantities of other metals with them. Processes of crystallisation must be used. Zinc is crystallised as the double ammonium zinc sulphate, cadmium as nitrate from a solution containing much nitric acid, tin as the double ammonium stannic chloride. In each case, after several crystallisations, a mother-liquor is obtained which contains only 1 or 2 per cent. of the principal metal, with practically the whole of the impurities.

The results found with Kahlbaum's metals are:—

	Lead per Cent.	Cadmium per Cent.	Iron per Cent.	Copper per Cent.	Zinc per Cent.
Zinc	0.003	0.005	0.0005	trace	...
Cadmium	0.005	...	0.001	...	trace
Tin	0.0013	...	0.0009	0.0013	Sulphur trace
Lead . . . . .	...	...	0.0006	0.001	...

A little oxide is probably present in each case, but was not estimated, except in the case of tin, which contained 0.0024 per cent. of tin oxide.

The author proposes to classify commercial metals in the following way. In a metal containing 10 per cent. of impurities the ratio is 1 : 10¹, with 1 per cent. it is 1 : 10², with 0.1 per cent. it is 1 : 10³, and so on. Metals are then said to be of the first, second, and third grade respectively. The metals containing under 0.01 per cent. of impurity, mentioned above, are thus of the fourth grade.

Separation of Copper from other Metals.—Copper is easily separated according to P. Jannasch and O. Routala,† by adding sufficient cane sugar to the solution to prevent the precipitation by sodium hydroxide, and adding hydrogen peroxide to the alkaline solution. An emerald-green solution is obtained, and on warming cuprous oxide is

* *Zeitschrift für anorganische Chemie*, 1912, vol. lxxiv. p. 407.

† *Berichte der deutschen chemischen Gesellschaft*, 1912, vol. xlv. p. 598.

precipitated quantitatively. The separation from arsenic, aluminium, zinc, tin, tungsten, &c., is perfect. The cuprous oxide must be filtered rapidly to prevent reoxidation. Arsenic may be estimated directly in the filtrate by precipitation with magnesium chloride. For the estimation of aluminium or zinc the sugar must be removed from the filtrate by evaporation with a mixture of 4 parts of nitric acid with 1 part of hydrogen peroxide (15 per cent.).

Thermal Analysis of Ternary Systems.—A paper by F. Hoffmann* describes a method of converting percentages by weight into atomic or molecular percentages in ternary systems. The process of calculation is tedious, and may be greatly shortened by the use of graphical methods. In binary systems the transformation is effected by a hyperbolic curve, whilst for ternary systems an acute-angled triangle is used. The method of constructing such a triangle is described. It is recommended that all ternary diagrams should be plotted with atomic or molecular percentages on account of the greater scientific clearness of such a method, and that a transformation triangle should be plotted on transparent paper, so that it may be laid on the diagram, and the percentages by weight read off. A still more general method of projection is described, which is also applicable to alloys of more than three metals.

Thermal Analysis of Quaternary Systems.—The method of constructing tetrahedral equilibrium diagrams of quaternary systems is discussed by N. Parravano and G. Sirovich,† the method being that of using plane sections passing through a vertex and parallel to one edge or plane sections parallel with one face.

Ultrafiltration.—The method of "ultrafiltration" through collodion membranes is recommended by R. Zsigmondy, E. Wilke-Dörfurt, and A. von Galecki‡ for filtering such solutions as those of colloidal metals, which pass through filter paper. The filters are prepared by pouring collodion on to a glass plate, allowing most of the ether to evaporate and immersing the plate in water, when the film is readily detached. It is supported on a filter paper on a porcelain vacuum funnel, and filtration is hastened by the use of a pump.

Use of the Mercury Cathode.—A paper by P. Baumann§ describes the best method of using mercury as a cathode in place of platinum in electro-analytical work. A glass cylindrical vessel is used, with a glass side tap just above the level of the mercury, the tap being replaced by a stopper during weighing. The mercury must be purified by washing with chromic acid solution, and is then conveniently distilled from an iron retort in a current of carbon dioxide. After filling into the vessel, and before weighing, it is washed with alcohol and ether

* *Metallurgie*, 1912, vol. ix. p. 133.

† *Atti della Reale Accademia dei Lincei*, 1911, vol. [v.] xx. (2), pp. 331, 412.

‡ *Berichte der deutschen chemischen Gesellschaft*, 1912, vol. xlv. p. 579.

§ *Zeitschrift für anorganische Chemie*, 1912, vol. lxxiv. p. 315.

(previously digested with alkali). The anode consists of two platinum gauze discs attached to a stout platinum spindle, and rotated at about 200 revolutions per minute. An electrical heating arrangement is provided for estimations at a high temperature.

By regulating the voltage at the terminals, many metals may be separated satisfactorily. The separation of mercury from bismuth or copper, and of silver from bismuth, takes place in about an hour at the ordinary temperature, whilst that of copper from antimony and of copper or bismuth from cadmium, requires a temperature of 70°.

II.—TESTING.

Method for Measuring Compressive Strength of Alloys.—The lack of information and necessity of standardisation with regard to compressive strength is pointed out by J. R. Huber,* who describes a method which gave "some very accurate comparative data on a series of non-ferrous alloys." The method was as follows:—

The test-pieces were cylindrical, 1 inch long and 1.128 inch diameter. A 50,000-pound Olsen testing machine was used. The end of the micrometer head holder was threaded to fit the upper test-bar holder of the machine. The lower one was removed and the 1 by 6-inch iron disc fastened in its place. The top of the bolt holding this disc was rounded off to form a smooth spot upon which to screw the micrometer down. The test-piece was placed between two hardened steel discs, 1 by 4 inches diameter.

In making the test, an initial load of about 200 pounds was applied to accurately seat the specimen, the beam brought to a balance, and the zero reading taken with the micrometer. The load was applied in increments of 200 pounds and a reading taken after each additional load.

III.—PYROMETRY.

Electrical Pyrometers.—Electrical methods of measuring and recording temperature are described by A. Schwark,† and the conclusion is drawn that iron-constantan couples may be made to give very accurate results up to 800°.

New Optical Pyrometer.—A photograph and brief instructions for using this instrument are given.‡ A small kerosene flame is used as a standard of comparison with the aid of a telescope and colour screens. It is stated to be rather less accurate than a first-class instrument but to give readings reliable to 10° Fahrenheit.

* *Metallurgical and Chemical Engineering*, February 1912, No. 2, vol. x. p. 96.

† *Zeitschrift des Vereins deutscher Ingenieure*, 1912, vol. lvi. pp. 223, 259.

‡ *Metallurgical and Chemical Engineering*, November 1911, No. 11, vol. ix. pp. 615-616.

Progress in Optical Pyrometry.—Constructional improvements and advantages of optical pyrometers based on the Paschen and Wein formula, which have resulted in the introduction of a “perfect type” into America, are described by A. Lenk.* The instrument has a temperature range of 650° C. to 7000° C.

Recent Advances in High Temperature Gas Thermometry.—For the subject matter of this lecture by A. L. Day† to the Faraday Society, see abstract, *Journal of the Institute of Metals*, No. 2, 1910, vol. iv. p. 324. The melting points of pure diopside and anorthite, in platinum crucibles, and an atmosphere of air, are given as $1391.2 \pm 1.5^\circ$ C. and $1549.5 \pm 2.0^\circ$ C. respectively. A new estimate of the melting point of platinum by thermo-electric extrapolation, is given as $1752 \pm 5^\circ$ C. A remarkably close agreement has been obtained between independent determinations by radiation methods of the temperature interval between the melting points of palladium and platinum :—

	Degrees Centigrade.
Nernst and von Wartenberg‡	204
Holborn and Valentiner § (Reichsanstalt)	207
Waidner and Burgess|| (Bureau of Standards)	207

Thermo-electric Pyrometer Improvement.—An improved thermo-electric temperature indicator is described by C. R. Darling,¶ which enables temperatures of all kinds to be measured accurately by automatically compensating for all alterations of the cold junction.

* *Metallurgical and Chemical Engineering*, March 1912, No. 3, vol. x. pp. 183-184.

† *Transactions of the Faraday Society*, Nov. 1911, Nos. 1 and 2, vol. vii. pp. 136-145.

‡ *Berichte der deutschen Physikalische Gesellschaft*, 1906, vol. iv. pp. 48, 146.

§ *Annalen des Physikalische*, 1907, No. 4, vol. xxii. p. 1.

|| *Bulletin of the Bureau of Standards*, 1907, vol. iii. p. 163.

¶ *Engineer*, October 27, 1911, vol. cxii. p. 432.

FURNACES AND FOUNDRY METHODS.

Ancient Bronze-Founding.—A short history of the bronze-founding of the ancients is given by H. Kühl,* who gives analyses of various ancient specimens of copper and bronze.

Behaviour of Fused Silica at High Temperatures.—A. Blackie† has investigated four varieties of fused silica, which he has designated unglazed, glazed, satin-like, and transparent, and has (1) ascertained the loss of strength after heating to high temperatures for definite periods: (2) examined the changes in structure which ensue, due to such treatment; (3) compared the coefficients of expansion of the transparent and opaque varieties. The following table gives the results obtained by the Strength Tests at high temperatures:—

Mean Furnace Temperature, Degrees Centigrade.	Period of Heating.	Strength in Kilogrammes (Centimetres) ²			
		"U" (Unglazed).	"G" (Glazed).	"S" (Satin-like).	"T" (Transparent).
Unheated	...	342	382	281	902
1124	8 hours	376	310	319	818
1122	3½ + 4½ hours	358	337	307	750
1188	4 hours	425	309	285	897
1186	8 "	369	311	277	802
1275	4 "	257	270	211	745
1353	4 "	218	186	188	339

Microscopic examination showed that the loss of strength is due to a gradual devitrification of the material with formation of a crystalline growth of tridymite.

The expansion tests showed that there is a slight temperature lag, and that the differences between the two classes are for practical purposes negligible. Some excellent photomicrographs of the material are given.

* *Giesserei-Zeitung*, 1912, vol. ix. pp. 119, 155.

† *Transactions of the Faraday Society*, Nov. 1911, Nos. 1 and 2, vol. vii. pp. 158-165.

Dust in Foundries.—A paper by E. Danneberg* describes the methods adopted in well-equipped modern foundries for the removal of dust, arising from sand-blasting and emery-grinding, from the air. The various forms of exhaust-fans and dust-catchers are described, together with the methods for connecting them with the sand-blasting and grinding machinery. The zinc-oxide fume in brass foundries is best removed by means of movable hoods, connected with the exhaust-mains by lobster-back joints. Where vigorous exhaust is used in cold weather, unpleasant draughts are set up, and it is then necessary to provide means of heating the air of the foundry. This is now done in many large foundries, and a description of the complete equipment is given.

Flameless or Surface Combustion.—The principles and applications of this method of heating are discussed by J. B. C. Kershaw.† In 1816 Davy discovered that a mixture of combustible gas and air forced into contact with a heated porous refractory material could be burned without production of any flame, yet with maintenance of a very high temperature. Bone‡ and McCourt have applied the method to the heating of crucibles, muffles, and steam boilers, with stated thermal efficiency of 90 to 95 per cent. The gas and air are forced into a mixing chamber and then through a porous refractory diaphragm at a speed greater than that at which combustion can propagate itself backwards through the mixture, which burns without flame within a layer $\frac{1}{8}$ inch thick at the free surface of the diaphragm, maintaining it in a high state of incandescence. A highly heated surface of this kind can be used for concentrating heavy liquids by surface evaporation. Diagrammatic representations of a crucible furnace, muffle furnace, and steam boiler are given. A charge of cast iron can be melted in the crucible furnace in ten minutes, starting with cold metal. Limits to temperatures attainable are set by the refractory materials themselves. Carborundum is quickly decomposed into silica and carbon dioxide, indicating temperatures of 2000° C. Once the proportions of gas and air are correctly adjusted, complete combustion ensues, and the maximum temperature possible to the gas is obtained. In the small steam boiler (ten tubes, 36 inches long by 3 inches wide) 1000 cubic feet of gas have been burnt per hour, and, starting all cold, steam at 150 pounds pressure was obtained in about twenty minutes, details of a trial run showing a net efficiency of 90 per cent.

Flow of Heat through Bodies—Flow of Heat through Contact Surfaces.—Tables of values of the thermal resistivities of a number of materials and of the flow of heat through contact surfaces and their equivalent thermal resistances, based on data collected from various sources, are given by C. Hering.§ Flow of heat can best be

* *Giesseri-Zeitung*, 1912, vol. ix. p. 1.

† *Metallurgical and Chemical Engineering*, Dec. 1911, No. 12, vol. ix. pp. 628-630.

‡ *Journal of the Institute of Metals*, No. 2, 1911, vol. vi. p. 352.

§ *Metallurgical and Chemical Engineering*, December 1911, No. 12, vol. ix. pp. 642-654; January 1912, No. 1, vol. x. pp. 40-44.

expressed by adopting the terms thermal resistance and resistivity or specific thermal resistance in place of conductance and conductivity, and by using the watt and thermal ohm as units. The thermal ohm * is that thermal resistance through which one watt of heat flow will pass for a temperature drop of 1° C. We then have (analogous to Ohm's Law)

$$W = \frac{T}{R}$$

where W = heat flow in watts, T = temperature difference in degrees Centigrade, and R = thermal resistance in thermal ohms. Also

$$R = \frac{rL}{S}$$

where r = specific thermal resistance (resistivity) in thermal ohms per centimetre cube, L = length, and S = cross section of thermal conductor.

By using these units, no conversion factors are necessary. Contact resistances between surfaces may be very high, as, for instance, that of the flames and the outside of the water tubes of a boiler, where the temperature gradient is enormous. It is known that a jointed graphite electrode may become red hot up to the joint, and yet be black on the other side of it. Invisible cracks in iron can be detected by measurements of the flow of heat up to and across them. The cases of solid to solid and to gas (furnace construction), metal to water (water cooling), water to metal to water, gas to metal to water (steam boilers), &c., are considered.

In a further paper † the whole subject of flow of heat, insulation of furnace walls, units, temperature coefficient of thermal resistance, advantage or otherwise of air spaces, joints, &c., is reviewed, and practical examples given of the method of calculating furnace losses as regards heat.

Fusibility and Volatilisation of Refractory Materials.—

O. Ruff and O. Goecke ‡ have made experiments, in an electrical resistance furnace, on the fusibility and volatilisation of a number of refractory materials. A description of the apparatus employed, together with illustrations, is given.

The fusion temperatures of the following substances were ascertained:—

	Degrees Centigrade.
Uranium carbide	2425
Vanadium carbide	2750
Iron protoxide	1419
Iron sesquioxide	1548
Magnetic oxide	1538
Lime	1995
Alumina	2020
Chromium sesquioxide	2059
Uranium oxide	2176
Zirconium oxide	2500

* *Metallurgical and Chemical Engineering*, January 1911, No. 1, vol. ix, p. 13.

† "Thermal Insulation of Furnace Walls," *Metallurgical and Chemical Engineering Journal*, February 1912, No. 2, vol. x, pp. 97-102. See also article by same author, *ibid.*, April 1911, No. 4, vol. ix, pp. 189-192.

‡ *Zeitschrift für angewandte Chemie*, vol. xxiv, p. 1459; *Revue de Métallurgie*, vol. viii, pp. 726-727.

In the course of the experiments the temperature of volatilisation of some of the substances was ascertained. Thus, alumina, which melts at 2020° under atmospheric pressure, commences to give off vapour at 1600° under a pressure of 6 millimetres of mercury, and at 1750° the vaporisation becomes relatively rapid. A similar anomaly occurs in the case of lime. In an atmosphere of nitrogen and at atmospheric pressure, crystalline needles of pure oxide sublime, even at a temperature of 1740°, although fusion does not occur until a temperature of 1995° is reached. On the other hand, under reduced pressure fusion does not occur until 2400° is reached.

History of Bell-Founding.—According to F. M. Feldhaus,* one of the oldest foundries in Europe is that of Aarau in Switzerland. The large bell of Freiburg Cathedral, weighing 3 tons, was cast there in 1367, and is still uncracked. Rheinfelden has a bell that was cast in the same foundry in 1350. The original book of recipes of Walther Reber, the founder of the Freiburg bell, is in the possession of the firm, which still continues the casting of bells.

Influence of Remelting on Bearing Metals.—The influence of remelting and of the rate of cooling on the properties of bearing metals is described by G. Goldberg † mainly on the basis of the recent experiments at Gross-Lichterfelde. The addition of magnesium or aluminium when remelting white metals is unnecessary, and if care is taken to avoid overheating, the change of composition on remelting should be insignificant. In bearing bronzes there is always a loss of tin, and the rate of cooling has a very great influence on the properties of the alloy. Repeated melting weakens these alloys.

Recovery of Copper Alloys from Dross.—The working-up of copper and brass dross is described by F. W. Siepke.‡ After mechanical and magnetic treatment to remove foreign material, the metallic portions are separated and melted, whilst the dross is briquetted, best with lime, and smelted in small, water-jacketed blast-furnaces. The product is either an impure copper or an inferior bronze. The removal of zinc can be regulated by varying the pressure of the blast. The copper may be partly refined in a reverberatory furnace, or, if much tin is present, the bronze obtained may be used for castings which are not required to be of specially pure material.

Shrinkage of Bronzes.—The influence of small quantities of other elements on statuary bronze (92 per cent. copper, 8 per cent. tin) has been studied by H. von Miller§ in view of the considerable shrinkage of the ordinary alloy. It is found that the shrinkage is not appreciably lessened unless as much as 10 per cent. of zinc is added, and this addition has a bad effect on the strength, and also on the capacity for

* *Geiserei-Zeitung*, 1912, vol. ix. p. 87.

‡ *Metallurgie*, 1912, vol. ix. p. 121.

† *Ibid.*, 1912, vol. ix. pp. 41, 83.

§ *Ibid.*, 1912, vol. ix. p. 63.

forming a patina. Aluminium, iron, nickel, cobalt, and silicon increase the shrinkage. The ease of working with tools is greatly increased by adding up to 2 per cent. of lead or antimony, whilst the patination is not interfered with. Manganese or nickel renders the alloy more difficult to work. The melting point is raised by the addition of iron, manganese, nickel, cobalt, or tungsten.

Use and Care of Crucibles in Foundry Practice.—Information as to use and care of graphite crucibles is given in a recent bulletin.* Finished crucibles are hygroscopic, and contain as a rule on arrival at the foundry 4 to 5 per cent. moisture. They require careful annealing; an average-sized crucible (No. 60) should be gradually heated to about 250° Fahrenheit, and maintained at this temperature at least 48 hours—immediate “scalps,” internal fractures, and “pin holes” are penalties of a too sudden heating. The use of tongs requires special notice: a crucible under its melting heat is plastic, and adjusts itself to any irregular shape to fit the tongs; care should therefore be taken in the second operation to place the tongs in the same position. The loss in crucibles in one shop where the same pair of tongs handled three sizes of crucibles would have paid for a dozen tongs in a short time. Nothing is more injurious to graphite crucibles than gases, notably sulphur dioxide, from impure fuel, particularly if the fuel be damp; imperfect combustion with oil or gas acts in the same way, the effect permeating the entire wall of the crucible. “Soaking,” necessitated through metal being ready long before the mould, also greatly reduces the life of crucibles.

Use of Equilibrium Diagrams in Foundry Practice.—In a lecture to foundrymen, W. Guertler † explains how the modern methods of metallography, and especially the method of embodying the results obtained in an equilibrium diagram, may be utilised in the practical work of the foundry. The lecture is illustrated by a large number of diagrams and photomicrographs.

* *Metallurgical and Chemical Engineering*, March 1912, No. 3, vol. x, pp. 182-183.

† *Giesserei-Zeitung*, 1912, vol. ix, pp. 137, 177.

STATISTICS.

Electro-Metallurgy in Norway in 1911.—It is stated * that the aluminium manufactured in Norway from imported alumina was about 1000 tons, and 6600 tons of zinc were also made in electric furnaces. The total value of electro-metallurgical products, exclusive of steel, was about £680,000.

French Aluminium Industry.—According to H. Grossmann † the production of aluminium in France increased from 6000 tons in 1909 to 9500 tons in 1910. The oldest French works are those of the Compagnie des Produits Chimiques d'Alais et de la Camarque, which began the manufacture of aluminium by St. Claire-Déville's method in 1861, and introduced the electrolytic process in 1897. The Société Electro-métallurgique française began with the Héroult process in 1888, and now has works at Froges, La Praz, Gardanne, and St. Michel de Maurienne, employing nearly 70,000 H.P. The two remaining works are the Société des Forces Motrices et Usines de l'Arve (1895), and the Société des Produits Electrochimiques et Métallurgiques des Pyrénées (1906), which now uses 12,000 H.P.

During 1911 the production of aluminium in France was 41,814 quintals, or practically the same as in 1910.‡ Of this 27,249 quintals were in ingots, and 14,565 quintals in rolled or drawn metal. The exports are chiefly to Switzerland and Germany. During the same year France exported 154,000 tons of bauxite.

Gold, Silver, Copper, and Lead in California.—According to figures published by C. G. Yale,§ made public by the United States Geological Survey, the mine output of California in 1910 had a total value of \$27,020,405.

	Weight.	Value in Dollars.
The production of gold was . . .		19,715,440
" " silver " . . .	1,840,085 fine ozs.	993,646
" " copper " . . .	48,700,756 lbs.	6,184,996
" " lead " . . .	2,870,977 "	126,323

* *Journal du Four Electrique*, 1912, vol. xxi. p. 145.

† *Zeitschrift für Elektrochemie*, 1912, vol. xviii. p. 162.

‡ *Journal du Four Electrique*, 1912, vol. xxi. p. 73.

§ *Metallurgical and Chemical Engineering*, October 1911, No. 10, vol. ix. p. 483.

These figures show a decrease in output of gold, silver, and copper compared with 1909, but a large increase in lead.

Gold, Silver, Copper, Lead, and Zinc Production in Western States in 1910.—The United States Geological Survey has issued the following official estimates of production of the principal metals in Western States: *—

	Arizona.	Colorado.	Idaho.	Montana.	Nevada.	Utah.
Gold (value, dols.)	3,149,366	20,507,058	1,096,842	3,730,486	18,878,864	4,032,085
Silver (fine ozs.)	2,566,528	8,509,598	7,369,742	12,162,857	12,479,871	10,466,971
Copper (lbs.)	297,491,151	8,359,535	7,037,292	284,808,553	64,359,398	127,597,072
Lead "	2,696,151	76,071,273	228,258,839	4,106,292	4,871,130	123,597,072
Zinc "	5,484,899	77,089,648	5,603,114	31,638,184	2,707,071	16,367,104
Total value, dols.	42,731,519	33,673,879	16,316,196	48,358,253	34,152,148	32,199,185
Tons mined	3,914,969	2,434,664	1,786,174	5,079,446	3,655,775	6,389,398

Mineral Production of Canada.—The Canadian Department of Mines,† Ottawa, have issued a preliminary report from which the following statistics of the mineral production of Canada for the year 1910 and 1911 are abstracted. The figures for 1910 are definitive; those for 1911 are subject to revision:—

	1910.		1911.	
	Quantity.	Value.	Quantity.	Value.
		Dollars.		Dollars.*
Metallic:—				
Copper, lbs.	55,692,369	7,094,094	55,848,665	6,911,831
Gold, ounces	493,707	10,205,835	...	9,762,096
Lead, lbs.	32,987,508	1,216,249	23,525,050	818,672
Nickel, lbs.	37,271,033	11,181,310	34,098,744	10,229,623
Silver, ounces	32,869,264	17,580,455	32,740,748	17,452,128
Other metallic products	...	510,081	...	409,674

* Dollar = 4s. 1½d.

Mineral Production of Southern Rhodesia in 1911.—The Colonial Office ‡ reports the mineral production of Southern Rhodesia for 1911 as follows, the corresponding figures for 1910 being added for comparison:—

* *Metallurgical and Chemical Engineering*, November 1911, No. 11, vol. ix, p. 592.

† *Board of Trade Journal*, March 28, 1912, vol. lxxvi, p. 671.

‡ *Ibid.*, p. 691.

	1910.		1911.	
	Quantity.	Value.	Quantity.	Value.
Gold, ounces	609,955	£ 2,568,198	628,521	£ 2,647,896
Silver, ounces	217,633	22,495	187,641	19,320
Lead, tons	746	8,463	639	7,821

Mineral Production of the Transvaal.—The Transvaal Chamber of Mines * reports the mineral production of the Transvaal for 1910 and 1911 as follows:—

	1910.		1911.	
	Fine Ounces.	£	Fine Ounces.	£
Gold	7,533,843	32,001,735	8,237,723	34,991,620
Silver	823,752	88,029	894,333	96,557

Mineral Statistics of Belgium.—The statistics of the metallurgical industry of Belgium † show that during the year 1909, 152 tons of lead ore, 1229 tons of zinc ore, and 6270 tons of manganese ore were produced. The number of zinc works in operation during the year was 13, and the production of zinc amounted to 174,490 tons. There were 5 lead and silver works in operation, and the amount of lead produced was 88,495 tons, while the production of silver amounted to 271,270 kilogrammes.

Production of Secondary Metals.—According to figures published by the United States Geological Survey, the production of metals ‡ recovered from scrap, dross, sweepings, &c., in 1910, was as follows:—

Copper	25,396 short tons.
Brass (remelted)	27,347 tons.
Lead	17,822 "
.. (recovered in alloys)	23,327 "
Spelter	33,040 "
.. (in alloys other than brass)	1,181 "
Tin	2,423 "
.. (in alloys)	3,092 "
Antimony	27 "
.. (in alloys)	1,529 "

Total value, \$45,525,500.

* *Board of Trade Journal*, April 4, 1912, vol. lxxvii. p. 35.

† *Annales des Mines*, vol. xx, p. 357.

‡ *Metallurgical and Chemical Engineering*, October 1911, No. 10, vol. ix. p. 559.

Quicksilver in California.—Fifteen quicksilver mines contributed to the California output in 1910, which amounted * to 17,211 flasks of 75 pounds each, valued at \$800,484.

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[Among the chapter headings are Ores, Reduction Methods, By-products, including scandium, titanium, tantalum and niobium, Manufacture of Sodium Tungstate, Tungstic Acid, Alloys and Compounds, Tungsten Filaments, Fire-proofing Cotton and other Fabrics, and Analytical Methods.]

MICHEL-ROUSSET, J. *La Coloration des Métaux. Nettoyage, Polissage, Patinage, Oxydation, Métallisation, Peinture, Vernissage*. 16mo., pp. viii+284, with illustrations. Paris: H. Desforges. (Price 2s. 6d.)

NAGEL, O. *Nagel's Gold Book—A Description of the Recovery of Gold from Sea Water*. New York: O. Nagel. (Price 8s. 4d.)

PRICE, W. B., and R. K. MEADE. *The Technical Analysis of Brass and Non-ferrous Alloys*. $5 \times 7\frac{1}{2}$ inches, pp. 267, with 17 illustrations. London: Chapman & Hall. (Price 9s.)

PROUST, G. *Recherche Pratique et Exploitation des Mines d'Or*. 16mo, pp. iv+112, with 14 illustrations. Paris: Gauthier-Villars. (Price 2s. 3d.)

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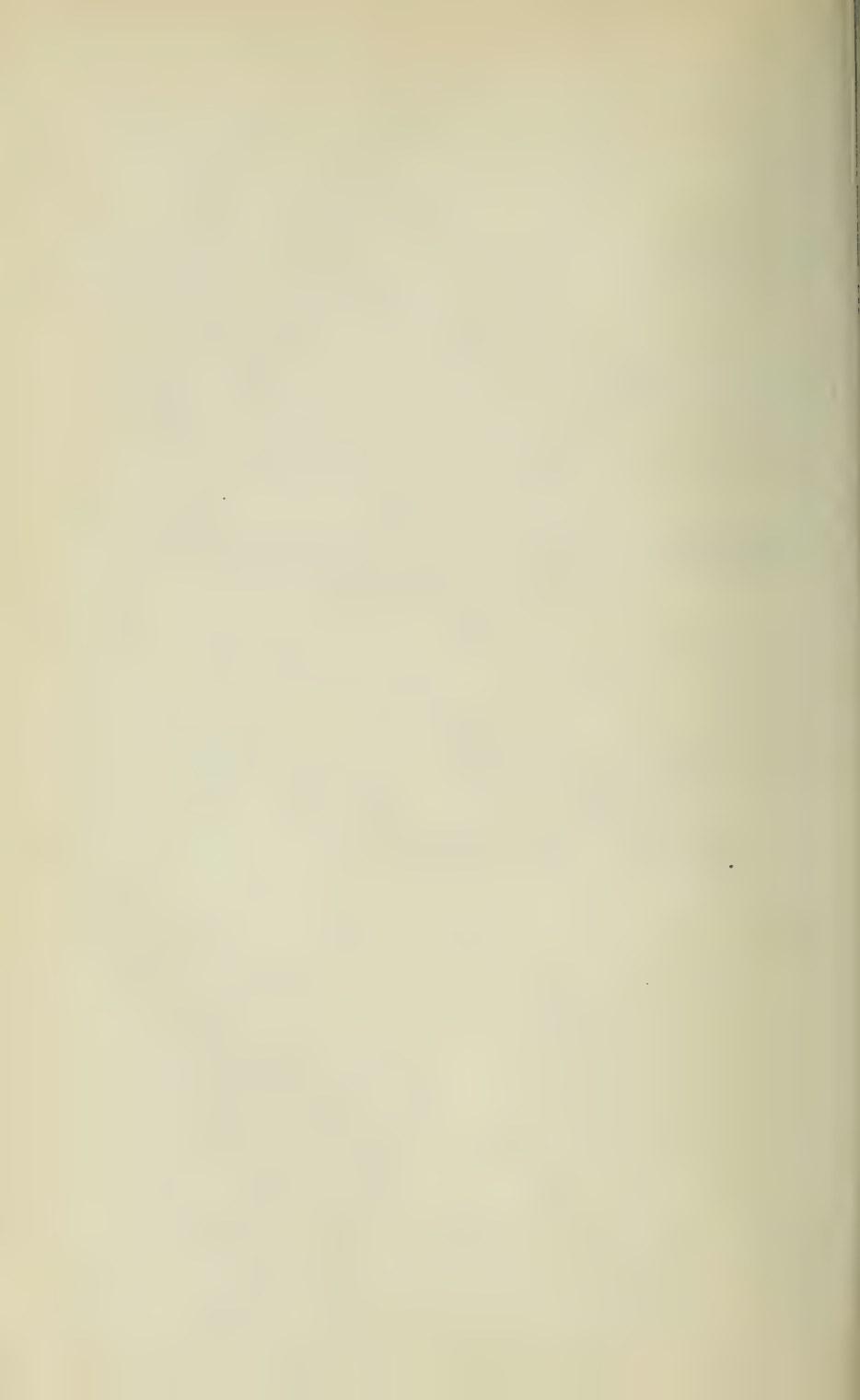
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SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION AND LIST OF MEMBERS.

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The Companies (Consolidation) Act, 1908

Memorandum of Association
OF
THE INSTITUTE OF METALS

1. The name of the Company is THE INSTITUTE OF METALS.
- 2 The Registered Office of the Association will be situate in England.
3. The objects for which the Association is established are :—
 - (a) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between Gilbert Shaw Scott of the one part, and the Association of the other part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.
 - (b) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the progress of inventions likely to be useful to the members of the Association and to the community at large.

- (c) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.
- (d) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.
- (e) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.
- (f) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sub-let, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.
- (g) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.

- (h) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon any of the property of the Association (both present and future), and to redeem and pay off any such securities.
- (i) To undertake and execute any trusts, the undertaking whereof may seem desirable.
- (k) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.
- (l) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.
- (m) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.
- (n) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whencesoever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any

member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Association. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges, and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot

be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members. Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

NAMES, ADDRESSES. AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,
Hastings House, Norfolk Street,
Strand, W.C.

The Companies (Consolidation) Act, 1908

Articles of Association
OF
THE INSTITUTE OF METALS

SECTION I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association.

4. Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

Honorary Members.—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (a) Students of Metallurgy; or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

6. Save as hereinbefore provided, applications for membership shall be in writing in the form following marked "A."

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned, _____, being of the required age and desirous of becoming a _____ Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this _____ day of _____, 19 ____.

.....	} Signatures of three Members.
.....	
.....	

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to

him of his election, as provided in the next clause hereof, his election shall be void.

8. Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form following marked "B."

FORM B.

SIR,—I beg to inform you that on the _____ you were elected a _____ Member of the Institute of Metals, subject to the payment by you of an entrance fee of £ _____, and of your first annual subscription of £ _____. These must be paid to me on or before the _____ day of _____ 19 _____, otherwise your election will become void.

I am, Sir, your obedient Servant,

.....Secretary.

9. In the case of non-election, no mention thereof shall be made in the minutes.

SECTION III.—COUNCIL AND MODE OF ELECTION

10. The affairs of the Association shall be managed and conducted by a Council, which shall consist of a President, Past-Presidents, six Vice-Presidents, fifteen Members of Council, an Hon. Secretary or Hon. Secretaries, and an Hon. Treasurer. All members who have filled the office of President shall be, so long as they remain members of the Association, *ex officio* additional members of the Council under the title of Past-Presidents. The first members of the Council shall be the following:—President, Sir Gerard Muntz, Bart.; Vice-Presidents, Prof. H. C. H. Carpenter, Prof. W. Gowland, Prof. A. K. Huntington, Engineer Vice-Admiral H. J. Oram, Sir Henry A. Wiggin, Bart. Ordinary Members of Council, T. A. Bayliss, G. A. Boeddicker, Clive Cookson, J. Corfield, R. Kaye Gray, Summers Hunter, Dr. R. S. Hutton, E. Mills, J. T. Milton, G. H. Nisbett, E. Ristori, A. E. Seaton, Cecil H. Wilson, Prof. T. Turner (Hon. Treasurer), W. H. Johnson (Hon. Secretary).

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of "Members of the Council" for "Directors" wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (a) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other

than one of those nominated by the Council. A list of candidates so nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the Scrutineers. The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council. And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

SECTION IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting. In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid. All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary

Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals*.

The Council shall have power to appoint a paid Secretary or Secretaries, and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

SECTION V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be 10 members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered

address within the United Kingdom) have not supplied to the Association an address within the United Kingdom for the giving of notices to them. No other persons shall be entitled to receive notices of General Meetings, but the Association may, but shall not be bound to give notice of General Meetings to members not entitled thereto in such manner as in the opinion of the Council may be practicable and convenient.

SECTION VI.—SUBSCRIPTIONS

28. The subscription of each ordinary member shall be two guineas per annum, and of each student member one guinea per annum. Ordinary members shall pay an entrance fee of two guineas each, and students an entrance fee of one guinea each. Provided that no entrance fee shall be required from any person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the Incorporation of this Association, and who had paid an entrance fee to the said Society. No entrance fee or subscription shall be payable in the case of Honorary members.

29. Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer, and for this purpose any subscription paid to the unincorporated Society for the period of July 1st, 1909, to June 30th, 1910, by any person who becomes a member of this Association shall go and be in satisfaction of any payment due in respect of membership of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice in the Form following marked "C" shall be given to such member, and if such subscription remains

unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

SIR,—I am directed to inform you that your subscription to the Institute of Metals, due _____, and amounting to £ _____, is in arrear, and that if the same be not paid to me on or before the day of _____, 19____, your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

.....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

SECTION VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act, 1908, as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

SECTION VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following:—

- (a) Communications made by members, students, or others.
- (b) Abstracts of papers appearing elsewhere.
- (c) Original papers appearing elsewhere.
- (d) Advertisements approved by the Council.

Every member shall be entitled to receive one copy of each issue of the Journal, delivered, post free, to his registered address.

SECTION IX.—COMMUNICATIONS

34. All communications shall be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

SECTION X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

SECTION XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

SECTION XII.—INDEMNITY

38. Every member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, &c., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,

Hastings House, Norfolk Street,

Strand, W.C.

LIST OF MEMBERS

Members of Council are indicated by italics.

Original Members' names are undated.

† Denotes Contributor of Paper.

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Cheyne House, Chelsea Embankment, S.W.

1910

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Pall Mall, S.W.

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Cedarcroft, Putney Heath, S.W.*

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1910

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1910

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Stud. Chem. Universität, Leipzig, Germany.

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INSTITUTE OF METALS.

Founded 1908.

Incorporated 1910.

To the Secretary,

I, the undersigned....., being of the required age and desirous of becoming aMember of the INSTITUTE OF METALS, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this.....day of....., 191 .

.....

Signatures
 of three
 Members.

The Council, having considered the above recommendation, present Mr.....to be Balloted for as a.....Member of the INSTITUTE OF METALS.

To be filled up
 by the
 Council.

CAXTON HOUSE,

WESTMINSTER, S.W.,

*Chairman.**Dated this.....day of.....191.....*

[FOR QUALIFICATIONS OF MEMBERS, SEE SECTION 1, OTHER SIDE.]

(It would be a convenience if the Candidate's Card were sent with this form.)

EXTRACTS FROM THE RULES.

(MEMORANDUM AND ARTICLES OF ASSOCIATION.)

SECTION I.—CONSTITUTION.

Rule 4.—Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members.

Rule 5.—*Ordinary Members* shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be:—

either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys;

or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be:—

either (a) Students of Metallurgy;

or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not.

Student Members shall not be eligible for election on the Council nor entitled to vote at the Meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

Rule 6.—Applications for membership shall be in writing in the form marked "A," and such application must be signed by the applicant and not less than three members of the Association.

Rule 7.—Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to him of his election, his election shall be void.

Rule 8.—Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form marked "B."

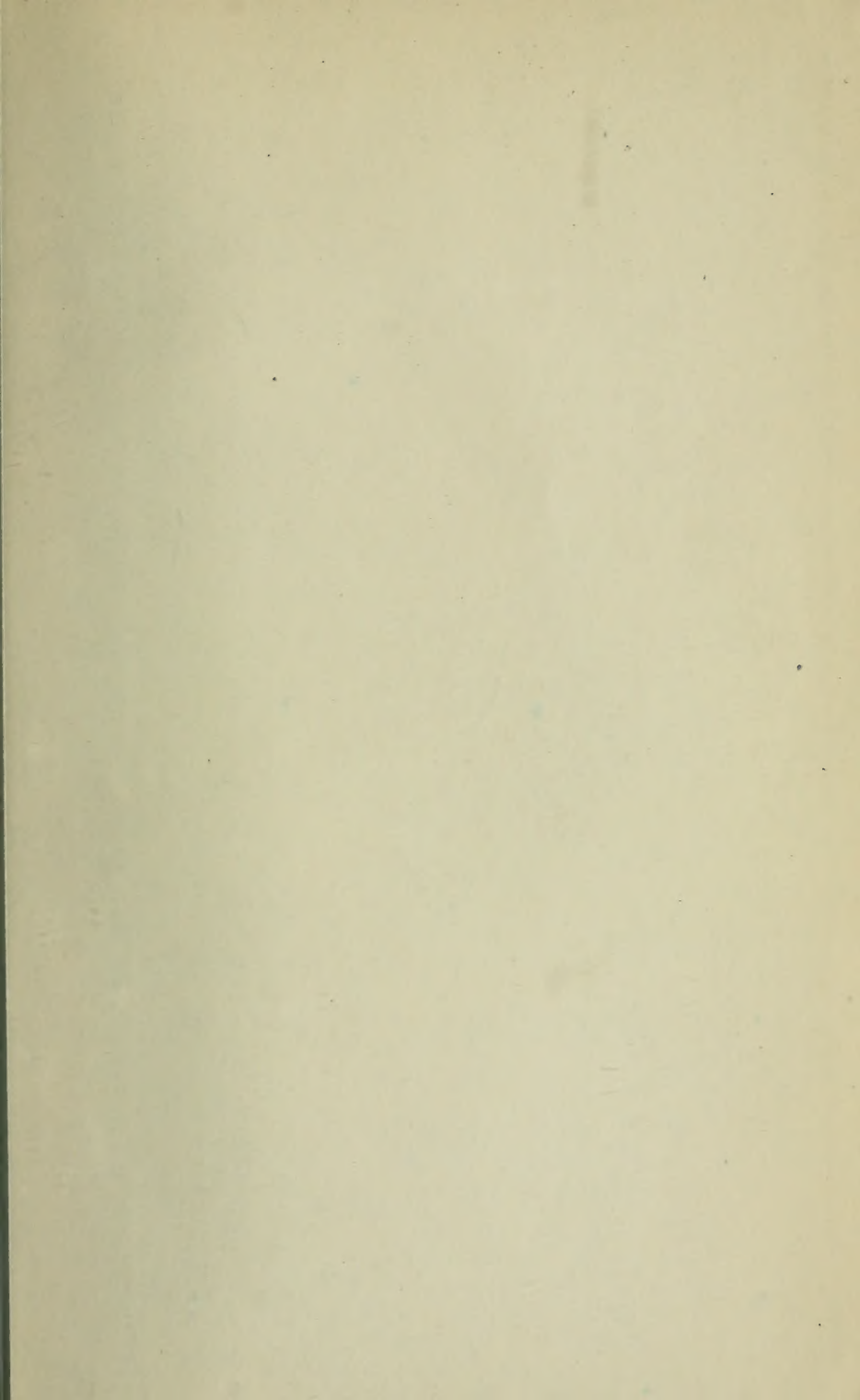
Rule 9.—In the case of non-election, no mention thereof shall be made in the minutes.

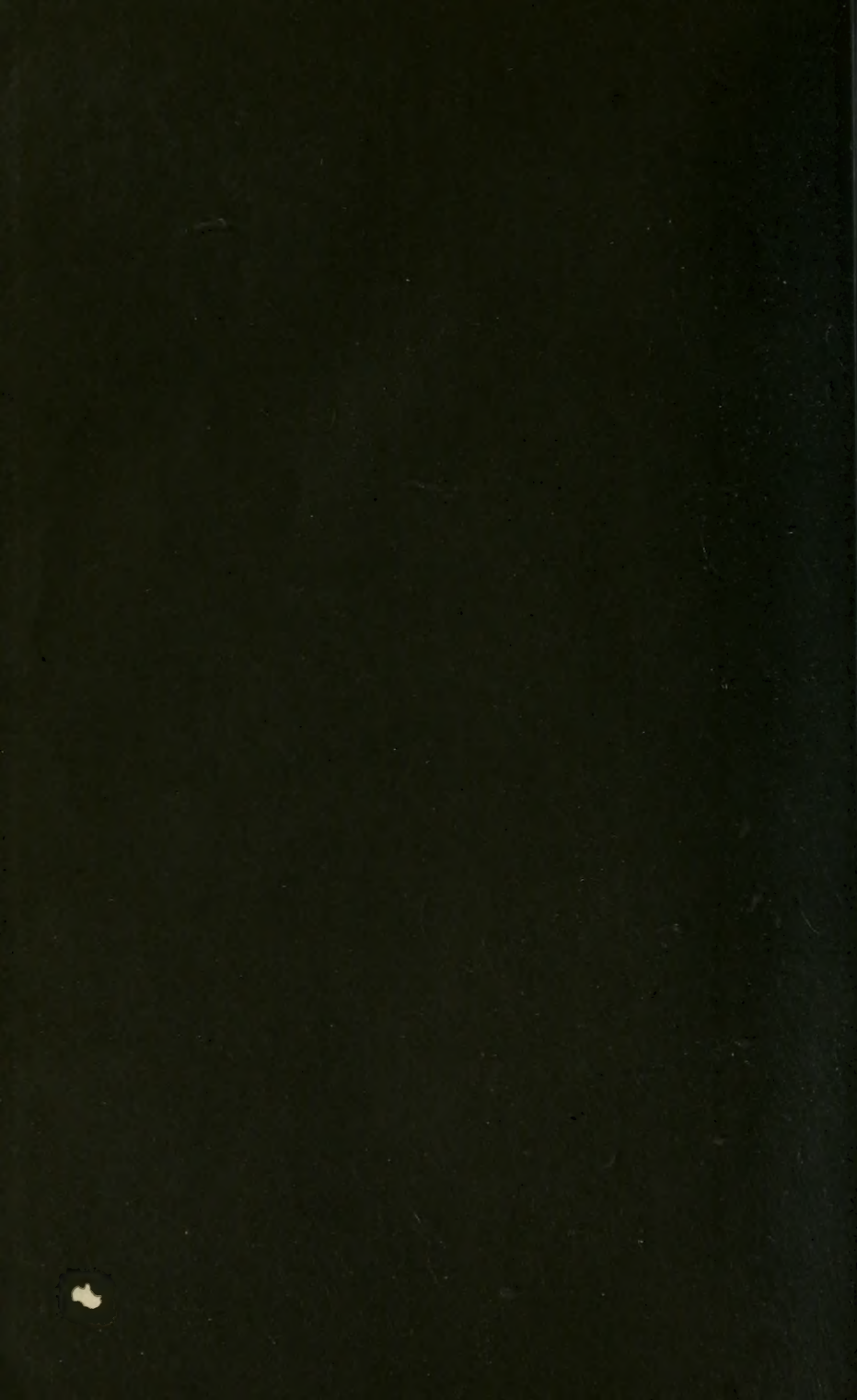
SECTION VI.—SUBSCRIPTIONS.

Rule 28.—The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum. Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each.

Rule 29.—Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer.

Rule 30.—Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice on the form following marked "C" shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.





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